INDUSTRIAL FURNACES

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Volume II

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PREFACE

In the present (third) edition of Volume II of the furnace men's bible, the general arrangement of the subject matter is identical with the arrangement in the second edition. A short chapter on safety measures has been added.

Within each chapter, changes of considerable magnitude have been made. Two thirds of the text was rewritten. Illustrations of lesser importance and of obsolete equipment were eliminated; 117 new illustrations were added.

Into Chapter I the latest available information (including cost data) on fuels and electrical energy has been incorporated. Among other changes, Chapter II describes many new burners, as well as improved mounting of electric heating elements and practical methods of calculating them. The electric heating of salt baths is described in detail. In Chapter III, the limits within which temperature of the charge can be controlled are more clearly explained than was done in the earlier editions. The description of instruments has been replaced by an explanation of underlying principles. In Chapter IV, the term "control of natural atmosphere" has been changed to "combustion control." Equilibrium charts are given for oxidation and reduction of several metals. A chart for carburization and decarburization of steels of various carbon contents is also given. An important section of Chapter IV deals with the application of protective atmosphere. Furnaces with autogenerated, hot, protective atmosphere are described. Control of composition of salt baths is also discussed. In Chapter V, many new labor-saving devices for moving material into, through, and out of furnaces are described and illustrated. Information is given on strength of link-belt chains and belts of woven wire. The equivalence of electric resistors and of radiant tubes is illustrated. The difficulties of automatic conveying in salt baths are explained. In Chapter VI, furnaces are compared on six different bases. Advantages and disadvantages of each combination are emphasized. New examples and new furnace types are included in the discussion. In one new example, a critical comparison is made with regard to first cost and operating cost. The changes in furnace design which the wide distribution of natural gas through pipe lines has wrought in the United States are discussed.

Chapter VII points out safety hazards and describes the measures for combating them.

In a technical book, it is impossible to follow the teachings of Horatius (died 8 B.C.), who said that literary work must be kept hidden for nine years before it is published. However, the author followed this precept in part by rewriting many of the revisions several times.

Since 1941, when the second edition was written, the author has had a great deal of experience with industrial furnaces. For that reason, a larger part of the present edition is based on personal experience than was true in former editions.

No general bibliography is included. A bibliography tells us what *was*—the reader wants to know what is *now*.

Credit is given both in the text and in the legends under the illustrations. The author wishes to thank all those who contributed to make this third edition both scholarly and up to date.

W. TRINKS

OHIOPYLE, PENNSYLVANIA
January, 1955

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INTRODUCTION

The function of industrial furnaces is to generate and apply heat in such a manner that the heated product will conform to certain specifications, with lowest cost of heating per unit of finished product.

The heat is generated either by combustion of fuel or by the conversion of electrical energy. Nuclear energy (atomic energy or fission energy) is a source of heat, but has at yet not been utilized in industrial furnaces. The selection of that source of heat which is best suited to a particular case necessitates the possession of knowledge concerning important properties of fuels and, to a minor extent, the equipment needed for their preparation. Chapter I was written with the aim of imparting that knowledge, together with general information concerning the cost of a given amount of heat when produced by different fuels. Two remarks are in order at this point: (1) the cost of heat energy is only a part of the total cost of heating, and (2) when money loses in value, as during a period of inflation, all fuel costs must be multiplied by the same inflation factor.

The devices for burning a fuel economically, with the correct quantity of air, vary widely with the nature of the fuel. Chapter II of the present volume deals exclusively with the equipment used to burn the different fuels and to convert electrical energy into heat. In that chapter, mention, of necessity, must be made of devices for controlling furnace temperature and furnace atmosphere; yet these same devices and the principles upon which they are based are important enough to be treated in separate chapters. Therefore, Chapter III has been devoted to the control of the temperature of the furnace and of the charge, whereas Chapter IV has been devoted partly to the effects of furnace atmosphere upon the charge, but mainly to the control of furnace atmosphere.

The requirement of low cost per unit of heated product has led to the development of a great variety of labor-saving devices in connection with furnaces, embracing the "handling" of the stock as well as the methods of furnace repair. In addition, automatic devices for bringing the fuel to the furnace, and for adjusting the supply of fuel to the requirements of the furnace, serve to economize labor. Chapter V deals with these devices in considerable detail and rounds out the description given in previous chapters.

Although "comparisons are odious," they must be made if the right type of furnace and the right kind of fuel (or energy) are to be selected for different purposes. With this fact in mind, the author has written Chapter VI, which aims to offer a critical comparison of furnace types and of fuels (or energy supply). It is based upon all previous chapters, including those in Volume I. A few examples are given which show the extent to which specific purposes and local conditions affect the choice of heat supply and of type of furnace.

Chapter VII deals with safety in the handling and use of fuels, in the use of electrical energy, and in the prevention of injury by mechanical forces.

CHAPTER I

FUELS AND ELECTRIC ENERGY

Furnace engineers and owners of furnaces are not interested in the length of time that was needed to produce fuels such as coal, oil, and natural gas. They are interested in the properties of fuels, in their availability, and in their relative costs. In accordance with this reasoning, the origin of fuels is omitted and stress is laid on properties, availability, and relative costs.

The following fuels are commonly burned in industrial furnaces:

I. Gaseous fuels.
   - A. Rich gases, such as natural gas, manufactured gas, coke-oven gas, water gas, refinery gas, butane, and propane.
   - B. Lean gases, such as producer gas (raw or cleaned), blast-furnace gas, mixed gas (coke-oven gas and blast-furnace gas).

II. Liquid fuels. Fuel oils, from the lightest (gasoline) to the heaviest (residual oil), tar, topped tar (pitch).

III. Solid fuels. Coal and coke for burning on grate, powdered coal, petroleum coke.

Electric energy, although not a fuel, takes the place of fuel, because it is easily converted into heat. Nuclear (atomic) energy has not yet been applied to heating industrial furnaces.

The important properties of commonly used fuels are given in Table I. On account of the unavoidable variations in the composition of fuels, the figures in the table are average values.

The expression "adiabatic flame temperature," or theoretical flame temperature, means that temperature which is obtained if the fuel is burned in the theoretical quantity of air, at constant pressure and in a heat-tight vessel. Adiabatic flame temperatures for different fuels and different conditions are shown in the graphs Figs. 1 to 10. In the calculation of these flame temperatures permanent dissociation was neglected.

The heat content of the products of combustion of unit quantity of various fuels is given in Volume I, Chapter III, in the section entitled Heat Carried out of Furnace by Products of Combustion.

Table II shows the percentage of permanent dissociation of CO_2 in a mixture of 21 per cent CO_2 79 per cent N_2 by volume, at atmos-

TABLE I

PROPERTIES OF FUELS

Fuel	Composition—Percentage by Volume (68 F and 14.7 Lb per Sq In. Abs Pressure)									Lower Heating Value, Btu per cu ft	Higher Heating Value, Btu per cu ft	Remarks
	Quantity, cu ft	Chemical Analysis (Dry)										
		CO_2	CO	CH_4	C_2H_4	C_2H_6	H_2	O_2	N_2			
Natural gas*	1			87.0		7.6			1.9	993	1097	$C_3H_8 = 2.7$; $C_4H_{10} = 0.8$
By-product coke-oven gas	1	2.2	6.9	34.2	2.6		47.3	0.3	6.0	500	561	$H_2S = 0.5$; $H_2O = 1.8$
Raw producer gas	1	7.5	20.5	3.0			12.5		56.5	138.7	147.8	From Pittsburgh coal. Tar vapor, 0.000625 lb per cu ft
Clean producer gas	1	9.71	19.03	2.78	0.19		13.48	0.02	54.79	128	137	
Blast-furnace gas	1	12.5	25.4				3.5		58.6	91.8	93.5	Water vapor, 1.45% by volume
Blue water gas	1	3.5	43.5	0.7			47.3	0.6	4.4	279	303	
Illuminating gas (coal gas)	1	4.6	5.5	36.6	4.6		42.3	4.6	1.8	539.9	597	
Illuminating gas (carbureted water gas)	1	2.9	18.2	23.9	8.1		38.3	4.8	3.8	506.3	533.2	
Mixed gas†	1	3.46	13.84	28.3	6.92		39.6	4.73	3.15	518.3	568.8	1 part coal gas, 2 parts carbureted water gas
Commercial butane	1									2977	3225	C_4H_{10}, 93%; C_3H_8, 7% (by volume)
Commercial propane	1									2371	2572	Figures based on 100% C_3H_8; commercial propane often contains other gases

* This is a typical composition. Depending on the location of the gas well, the composition of natural gas varies within wide limits.

† Mixed gas here means a mixture of retort gas and of carbureted water gas. In steel-works practice, mixed gas commonly refers to a mixture of coke-oven gas and of blast-furnace gas.

TABLE I—*Continued*

Fuel	Composition — Percentage by Weight								Btu per Lb	Btu per Lb	Remarks
	Quantity, lb	C	H_2	O_2	N_2	S	H_2O	Ash			
Coal (bituminous, low ash)	1	79.86	5.02	4.27	1.86	1.18		7.81	14,080	14,490	
Coal (bituminous, high ash)	1	70.00	5.00	8.00	2.00	2.00		13.0	12,410	12,780	
Lignite (dry)	1	59.9	4.37	18.64	1.22	2.65		13.22	9,897	10,082	Average composition
Lignite (wet)	1	41.93	3.06	13.05	0.85	1.86	30.0	9.25	6,917	7,063	
Coal tar	1	86.7	6.00	3.1	0.116	0.745	3.2	0.097	15,827	16,341	
No. 2 fuel oil	1	86.5	12.6			0.7	O_2+N_2+ash$=0.2$		18,410	19,500	
No. 6 fuel oil	1	86.8	10.2			2.0	O_2+N_2+ash$=1.0$		17,410	18,300	
Petroleum coke (ash and moisture free)	1	93.4	3.8	0.9	0.9	1.0			15,820	16,150	Ash, 1% (dry basis)

TABLE I—*Continued*

Perfect Combustion with Theoretical Air

Fuel	Requires Lb per cu ft of Gas	Products of Perfect Combustion, lb per cu ft of Gas				Adiabatic Flame Temperature, F‡
	Air	CO_2	H_2O	N_2	Total	
Natural gas*	0.804	0.132	0.1005	0.614	0.846	3660
By-product coke-oven gas	0.380	0.057	0.061	0.293	0.411	3700
Raw producer gas (bituminous)	0.0897	0.0379	0.0092	0.1104	0.1575	2920§
Clean producer gas	0.0823	0.0370	0.0095	0.0962	0.1427	2930
Blast-furnace gas	0.0524	0.0440	0.0017	0.0835	0.1292	2600
Blue water gas	0.1689	0.0550	0.0232	0.1331	0.2113	4100
Illuminating gas (coal gas)	0.387	0.0648	0.0592	0.2985	0.4225	3740
Illuminating gas (carbureted water gas)	0.352	0.0715	0.0491	0.2730	0.3936	3810
Mixed gas†	0.362	0.0689	0.0521	0.2810	0.4020	3800
Commercial butane	2.344	0.378	0.194	1.812	2.384	3640
Commercial propane	1.838	0.289	0.1643	1.416	1.869	3660

TABLE I—*Continued*

Fuel	Air, Lb per lb of Fuel	CO_2	H_2O	N_2	Total, Lb per Lb of Fuel	Adiabatic Flame Temperature, F‡
Coal	10.8	2.953	0.452	8.318	11.723	4020
Coal	9.53	2.61	0.45	7.34	10.40	3960
Lignite (dry)	7.72	2.25	0.3933	5.045	8.588	3740
Lignite (wet)	5.405	1.575	0.5755	4.163	6.313	3430
Coal tar	12.05	3.18	0.572	9.30	13.05	4050
No. 2 fuel oil	14.43	3.17	1.134	11.103	15.41	3900
No. 6 fuel oil	13.64	3.18	0.912	10.50	14.59	3820
Petroleum coke	13.13	3.43	0.342	10.35	14.12	3840

‡ See also Figs. 1 to 10.

§ This value is meaningless, and is given only for the sake of completeness. Raw producer gas is always hot at entrance to furnace. Adiabatic flame temperature is about 3150 F, if producer is located close to furnace.

pheric pressure. At low partial pressures, the dissociated fraction may be twice as high.

It is evident that the effect of permanent dissociation is negligible for the temperatures encountered in industrial heating furnaces. It assumes importance in high-temperature melting furnaces, but these are not considered in the present volume.

TABLE II

Temperature, F	Percentage Dissociation of CO_2
2250	0.07
2500	0.24
2750	0.70
3000	1.65

If a mixture of two fuels is burned, the adiabatic flame temperature may be taken to lie proportionally between the flame temperatures of the individual fuels. If, for example, a half-and-half mixture of blast-furnace gas and of coke-oven gas is burned in 400 F air, the adiabatic flame temperature is, sufficiently correct for practical purposes, $\frac{1}{2}(3960 + 2750) = 3355$ F.

For a fuel of a given type, relatively great differences in composition result in very small differences of adiabatic flame temperature because a lean fuel has to heat a smaller weight of products of combustion than a richer fuel has to heat.

The adiabatic or theoretical flame temperature is never attained in furnace practice. If combustion is completed in a heat-tight chamber, the outlet opening of which is protected against excessive radiation, 95 to 96 per cent of the theoretically possible temperature rise can be realized; however, such an arrangement has no utility, because no material can be heated under these conditions.

Whenever a charge is being heated in a furnace, the products of combustion, *during combustion*, give up heat to the charge. As a result, the actually attained flame temperature is about 70 per cent of the theoretically attainable. (In Europe, the ratio of actual temperature rise to theoretically possible temperature rise is called "pyrometric efficiency.") It follows that a very high flame temperature can be reached if vast volumes of rapidly produced products of combustion pass through the furnace. Low flame temperatures result if slow-burning gases give up heat to the charge. The value of 70 per cent ("pyrometric efficiency") is an average value only. It varies from a low value of 50 per cent to a high value of 85 or even 90 per cent.

Very often, combustion occurs either with a deficiency or with an

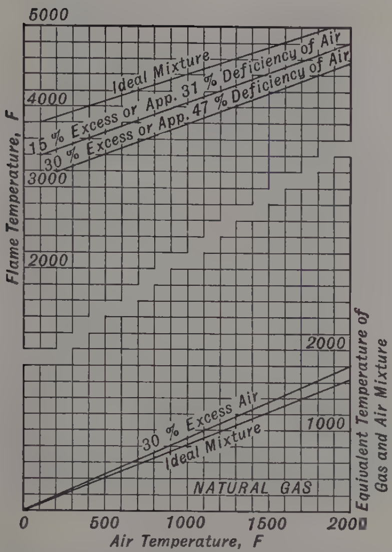


Fig. 1. Adiabatic flame temperatures of natural gas, with air preheated to various temperatures.

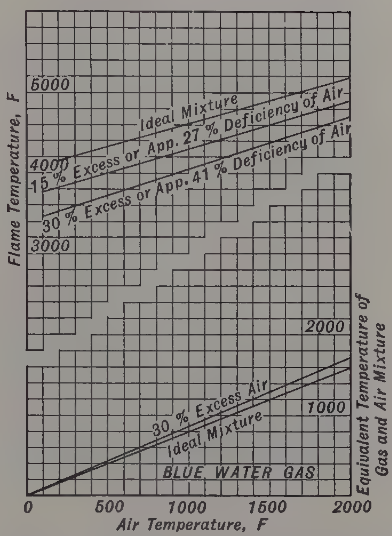


Fig. 2. Adiabatic flame temperatures of blue water gas, with air preheated to various temperatures.

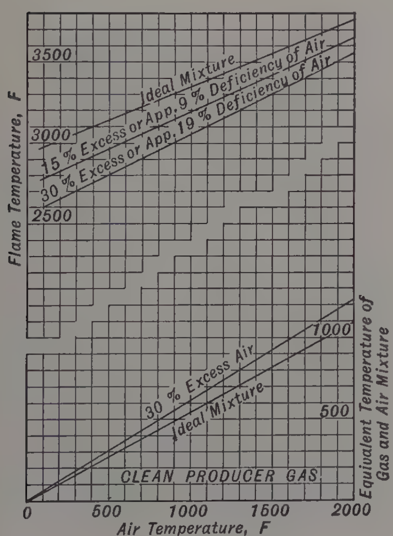


Fig. 3. Adiabatic flame temperatures of clean producer gas, with air preheated to various temperatures.

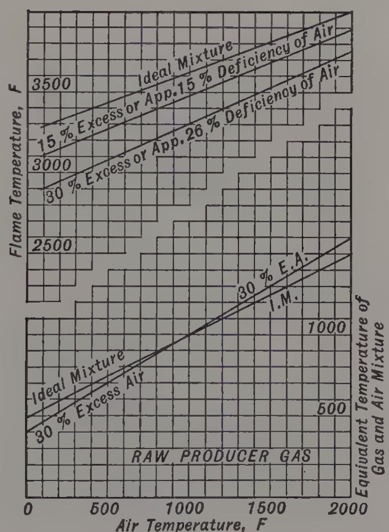


Fig. 4. Adiabatic flame temperatures of raw producer gas, gas initially at 1000 F; air preheated to various temperatures.

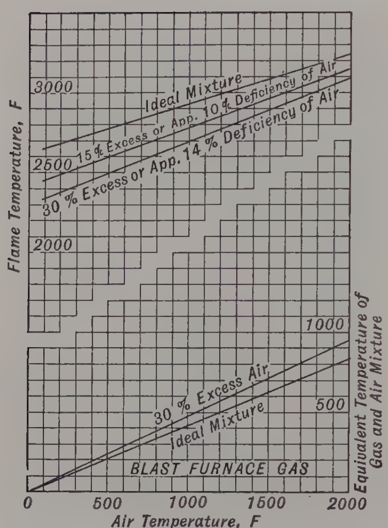


Fig. 5. Adiabatic flame temperatures of blast-furnace gas, with air preheated to various temperatures.

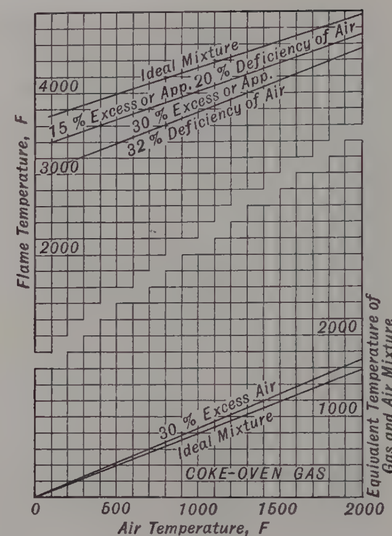


Fig. 6. Adiabatic flame temperatures of coke-oven gas, with air preheated to various temperatures.

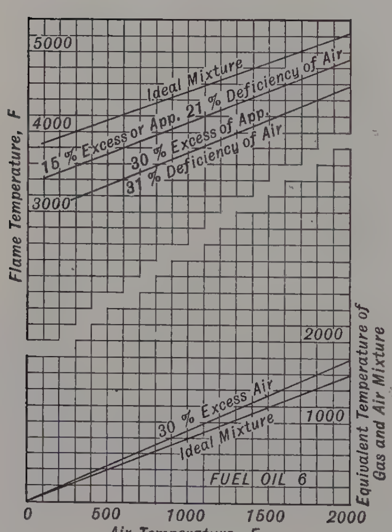


Fig. 7. Adiabatic flame temperatures of fuel oil 6, with air preheated to various temperatures.

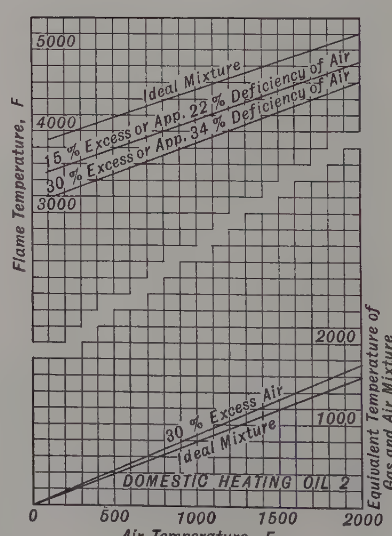


Fig. 8. Adiabatic flame temperatures of fuel oil 2, with air preheated to various temperatures.

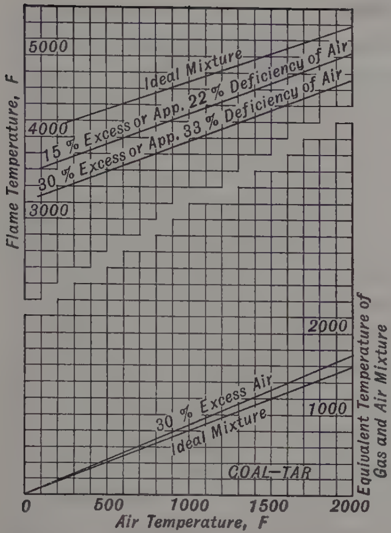


Fig. 9. Adiabatic flame temperatures of raw coal tar, with air preheated to various temperatures.

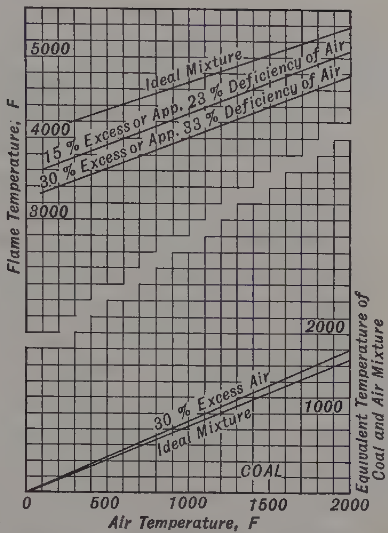


Fig. 10. Adiabatic flame temperatures of coal, with air preheated to various temperatures.

excess of air. The effect of departures from the theoretical volume of air may be read from Figs. 1 to 10.

Gaseous Fuels

Of the three types of fuels (gaseous, liquid, and solid), gases offer the greatest number of advantages. They are easily transported to any number of furnaces. Most of them can be burned without smoke, even in a cold furnace. They can be mixed with air in proper proportion without previous preparation; the rate of their flow can be accurately measured; they allow easy control of temperature, of furnace atmosphere, and of temperature distribution.

Natural Gas. The name indicates that this gas is not man-made, or artificially made; it can be used in the condition in which it comes out of the ground. In the United States, natural gas is found in many states and is piped to other states.

An excellent tabulation of the analyses and of the heating values of natural gas from wells in all states that produce natural gas is contained in Bulletin 486 of the United States Bureau of Mines, "Helium-Bearing Natural Gases of the United States," by Anderson and Hinsom, published in 1951. In the 141 pages of tables, natural gases

are listed with (higher) heating values ranging from 354 to 1500 Btu per cubic foot. Since the volume of air required for combustion of unit volume of gas is approximately proportional to the calorific value of the gas, the air requirements of natural gases vary over a wide range. Obviously, the natural gas of Table I is only an average. However, that average coincides with most natural gases that are distributed through pipe lines, because Texas natural gas is now distributed over long distances and is mixed with "near-by" gases. Although this blending does not obliterate differences in composition, it effectively reduces them to a small value.

Natural gases that have a high calorific value contain casing-head gasoline, butane, and propane. After removal of these constituents the gas is called a dry gas. This term does not refer to water vapor.

Natural gas appears to be the most desirable fuel for industrial furnaces. It has been piped to industrial centers in almost every state in the union. The high heating value of average natural gas allows transportation through comparatively small pipe lines. The gas is clean and, with very few exceptions, free from sulphur. Intermittent use causes no stand-by losses, because the earth is not only a natural but also an artificial reservoir. The latter statement refers to the practice of pumping natural gas that comes from distant wells into abandoned near-by gas wells during the summer. In spite of this excellent practice, demand exceeds supply on very cold winter days in districts which are located at some distance from freely producing wells. Since domestic consumers of gas cannot be expected to install stand-by equipment, and since domestic rates for gas are 50 to 60 per cent higher than industrial rates, industrial users face this dilemma: Either stand-by equipment for burning another fuel must be installed, or else the furnaces are shut down on cold days.

Since natural gas consists almost entirely of hydrocarbons, it can produce a luminous flame, if luminosity is needed. The high content of hydrocarbons forbids preheating natural gas in regenerators or recuperators, because the hydrocarbons are broken down at high temperatures and clog the passages with soot. Moreover, heat salvage by preheating natural gas is negligible, because the weight of the gas is less than one fifteenth of the weight of the fuel-plus-air mixture. A mixture containing a small amount of natural gas and a large amount of blast-furnace gas can be preheated without formation of soot, presumably because the liberated carbon can combine with CO_2 in the blast-furnace gas.

The cost of heat units in natural gas depends upon several variables, the most important being the cost of installing pipe lines and of oper-

ating compressor stations, which are necessary because of the distance between producing wells and point of consumption. In the United States, the Pittsburgh (Pennsylvania) district is fairly typical, because it receives natural gas from Pennsylvania, from West Virginia, and from Texas. In the Pittsburgh district the cost of 1000 cu ft of natural gas is $1.50, if less than 1000 cu ft are consumed in a month. It drops down in steps to about 40 cents per 1000 cu ft, if more than 20 million cu ft are consumed per month. In 1952, the blended gas in the Pittsburgh district had a lower heating value of 941 Btu at 60 F, and 14.7 psia.

It may be mentioned that the analysis of natural gas, as commonly reported, shows a certain percentage of "ethane." Actually, the gas contains small percentages of more complex hydrocarbons. They are replaced by that amount of ethane that has the same calorific value.

Coke-Oven Gas. This gas is produced by high-temperature distillation of bituminous coal or of a mixture of bituminous and semibituminous coals. As a rule, this most excellent fuel is not available to the general public because it is made in coking plants which are adjuncts to steel works, and because steel works have, in general, use for more gas than the coke works produce. Its use is therefore limited to furnaces in steel works. There are a few exceptions to this rule as, for instance, in steel plants that make additional coke for other industries. Such cases, however, are rare. Conditions are different in some European countries, such as Germany, where the gas is produced at the coal mines and is distributed through pipe lines over long distances. In that country, lean ores require much coke; and the blast-furnace gas is utilized so economically that a surplus of coke-oven gas exists.

The following data on coke-oven gas are of interest to the user: One pound of straight, high-volatile coal furnishes 3300 Btu in the total volume of by-product gas. From 1100 to 1250 Btu are required to coke 1 lb of coal, while 200 Btu are contained in the benzol which is extracted from the gas. This leaves, roughly, 1900 Btu in the surplus gas which is made from 1 lb of coal. With excellent regenerative efficiency and capable oven supervision, the latter value (1900 Btu) can be raised to 2000 Btu on straight, high-volatile coal. With low-volatile coals, such as those coming from the Pocahontas and Somerset fields, the calorific content of the gas drops to 2500 Btu per lb of coal, while the heat demand for coking remains constant, namely, 1200 Btu per lb of coal; on the other hand, only 100 Btu go into the benzol so that 1200 Btu are available in the surplus gas from

each pound of coal. From these figures, the amount of heat available from a pound of mixed coal can be computed for any mixture.

The information contained in these data is probably more reliable than any figure giving the amount of surplus gas because leaks into or out of the system will affect the quantity of surplus gas. However, some engineers prefer the information in that shape, and for them the following data will be of interest. One short ton of straight, high-volatile (Pittsburgh) coal produces 6300 to 6400 cu ft of surplus gas.

The heating value of coke-oven gas made from Pittsburgh coal averages about 565 Btu per cu ft (higher heating value at 62 F, 30-in. barometer). The corresponding value for mixed coal is about 540 Btu. Both figures apply to debenzolized gas. Typical analyses of the gas are as follows:

	CO_2	C_2H_4	O_2	CO	H_2	CH_4	N_2	Sp Gr
Straight Gas								
Before removing benzol	2.2	3.5	0.3	6.8	47.3	33.9	6.0	0.44
After removing benzol	2.2	2.6	0.3	6.9	47.3	34.2	6.0	0.42
Lean Gas								
Before removing benzol	2.1	2.0	0.3	6.0	57.0	27.0	5.6	0.38
After removing benzol	2.1	1.0	0.3	6.1	57.5	27.3	5.7	0.35

The composition varies considerably with the kind of coal, time and temperature of coking, air infiltration, the quantity of oil sprayed on the coal, and still other factors; no analysis can apply to all conditions. Wherever possible, the composition of the particular gas to be dealt with should be ascertained by test.

The low value of the specific gravity of coke-oven gas (averaging about 0.39 referred to air) is due to the high content of hydrogen and methane. On that account also, the lower heating value is comparatively low; for the "straight gas" given above, it is about 508 Btu per cu ft. The presence of a small percentage of illuminants insures a luminous flame, unless the gas is thoroughly mixed with the air before combustion begins. To complete the statement of the properties of by-product coke-oven gas, it should be mentioned that each 100 cu ft of gas contain 350 grains of hydrogen sulphide and 15 grains of carbon disulphide.

The cost of 1,000,000 Btu is of importance with coke-oven gas, as with other fuels. But, in arriving at a cost, a great difficulty arises because the gas is usually (at least in the United States) considered as a by-product and, for that reason, "costs nothing." In most steel plants by-product gas is valued to equal the cost of the fuel which it replaces. In 1952 it was valued at 16 cents per 1000 cu ft in steel

works situated along the Monongahela and Ohio rivers, if used for metallurgical purposes. If the gas is burned under steam boilers, it replaces coal and is worth only eight cents. The difference represents the cost of making gas from coal. The cost of coke-oven gas is almost directly proportional to the cost of coal. The cost changes almost 50 cents per 1000 cu ft for every dollar change in the cost of a ton of coal.

In judging the quantity of coke-oven gas which is available in a given steel plant, we must not lose sight of the amount which must be sacrificed for purposes of regulation. At one time or another the supply of fuel to a furnace must temporarily be increased above the average value and there must be a source from which it can be diverted. As a rule, that place is at the boiler plant, where 6 to 8 per cent of the coke-oven gas is burned under average conditions. If the demand for gas at the furnaces is increased, less gas goes to the boilers. The deficiency at the boilers is made up by burning more coal.

Water Gas. Water gas is generated when steam is blown through a bed of glowing carbon. At low temperatures (about 930 F) carbon dioxide and hydrogen are formed, while at high temperatures (1600 F or above) carbon monoxide and hydrogen are formed. Between the two temperatures (930 and 1600 F) carbon monoxide, carbon dioxide, and hydrogen are formed. The process abstracts heat from the fuel bed and lowers its temperature. If the temperature is allowed to drop too much, an excessive amount of undecomposed water vapor passes into the water gas.

At the present time no commercially useful process exists to make water gas continuously in the same producer or generator because the breaking up of the steam into hydrogen and oxygen requires more heat than is given off by the combination of carbon and oxygen. The process must be intermittent; the fuel is heated to a high incandescence by an air blast and then steam is passed through the same generator until the temperature has been reduced almost to the point below which good gas can no longer be obtained. The process thus calls for alternate "blows" with air and "runs" (gas-making periods) with steam.

The intermittent feature of the gas-making process necessitates either the use of two generators with a small gas holder or else the use of one generator with a large gas holder. If, with one generator and a large gas holder, the gas is to be used at the average rate at which it is made, the capacity of the holder need not exceed the volume produced during an hour's production. Water-gas sets are now operated automatically, and the human element is eliminated.

The automatic control is capable of such fine adjustment that short cycles (less than 2 min) can be obtained. The result is a gas of uniform quality.

If the sensible heat of the gases leaving the generator is utilized in making steam for the run (steam blow), the thermal efficiency of the gas-making process may reach 70 per cent. Otherwise, the efficiency lies between 50 and 55 per cent.

As a rule, water gas is cleaned before entering a furnace. It passes through a seal pot, a shower scrubber, and, if the requirements are exacting, through equipment that removes hydrogen sulphide.

Water gas is rich in carbon monoxide and, for that reason, is poisonous. It burns with a blue flame. The term blue water gas is generally used to distinguish it from carbureted water gas, which is made by vaporization and cracking of gas oil in an atmosphere of hot (blue) water gas, and which burns with a luminous flame.

Water gas has the highest adiabatic flame temperature of all industrial gases that are intended for quantity use. For that reason, it was, at one time, in great demand for "hammer welding." Electric welding having largely replaced flame welding by water gas, the use of this gas has dwindled. Although water gas is a desirable fuel, the equipment and labor for generating it are so high in cost that it is used as a last resort.

City Gas. In cities where natural gas is not available, artificial gas is used in industrial furnaces. This gas, often referred to as "city gas," "town gas," or "manufactured gas," may be one of several gases: coal gas (also called retort gas), water gas, oil gas, or a combination of any two or all of them. A combination of water gas and oil gas constitutes carbureted water gas. The mixture which is most commonly distributed through the gas mains of cities consists of carbureted water gas and coal gas. In some municipal plants these gases are not mixed but are sent through the mains separately.

Coal gas (retort gas) is made by the destructive distillation, or "carbonization," of coal in externally heated ovens or retorts. Bituminous coal is used in this process, and the resulting by-products are coke, retort carbon tar, and ammoniacal liquor. One net ton of coal yields an approximate average of 10,000 to 11,000 cu ft of gas and between 1200 and 1300 lb of coke. The calorific value of this gas is in the neighborhood of 600 Btu per cu ft. The gas produced requires purification and is, therefore, passed through scrubbers to take out any solid matter which may be present; sulphur compounds are also removed.

To form carbureted water gas, oil gas (made by waste heat from

the blue-gas generator) is added to the water gas. The gas thus formed has a calorific value of approximately 550 Btu per cu ft.

An average chemical composition and the ideal flame temperatures of coal gas, carbureted gas, and a 1 to 2 mixture of the two are shown in Table I. The cost of city gas (mixed gas, manufactured gas) varies with the place where it is made and with the number of cubic feet that are consumed per month.

In an industrial district of New Jersey the following rates prevailed in 1953:

First 100,000 cu ft per month or less	$100
Next 200,000 cu ft per month	5.0 cents per 100 cu ft
All additional	4.5 cents per 100 cu ft

The calorific value of this gas is 525 Btu per cu ft.

The rates in an industrial district of Massachusetts are similar.

First 500,000 cu ft per month	6.0 cents per 100 cu ft
Next 500,000 cu ft per month	5.5 cents per 100 cu ft
All additional	5.0 cents per 100 cu ft

In this case, there is also a demand charge which is based on the maximum consumption of gas in any 24 hours of December, January, or February. The following figures give the demand charge:

First 5,000 cu ft in 24 hours	$35
Next 20,000 cu ft in 24 hours	40 cents per 100 cu ft
All additional	20 cents per 100 cu ft

All rates for manufactured gas are tied to the cost of bituminous coal.

Refinery Gas. In the process of cracking petroleum, petroleum coke and refinery gas are by-products. The gas contains hydrogen and hydrocarbons of many different compositions. The heating value ranges between 1300 and 2000 Btu cu ft, although in most refineries the range is narrower. A typical range is from 1400 to 1700 Btu/cu ft. If a manufacturing plant with industrial furnaces is located close to a well-established oil refinery, purchase of refinery gas by the manufacturer is beneficial for both manufacturer and refiner.

Producer Gas. In the present-day meaning of the term, producer gas is that gas which is obtained by blowing a mixture of steam and air through a deep bed of glowing coal or coke. If air alone is blown through the fuel bed, air gas is made. Variations in the air-steam ratio produce variations in the composition of the gas. The composition of the gas also varies with the kind of fuel that is gasified, because the making of producer gas involves three steps, namely,

drying (giving off water vapor), distillation of volatile matter, and gasification of carbon. Evidently gas made from coke or anthracite will contain none of the distillation products of coal, whereas gas made from bituminous coal will contain a great variety of hydrocarbons.

The abundance of oil and of natural gas in the United States has greatly reduced the use of producer gas. It is almost an emergency fuel that is used when and where more convenient fuels are not available.

Raw Producer Gas. The gas that comes directly from the producer is called raw producer gas. It is commonly burned in large furnaces without any cleaning or cooling. In that event, producer and furnace (or furnaces) should be placed as close together as possible in order to utilize the sensible heat in the gas and the calorific value (combustion heat) of the uncondensed tarry vapors.

The use of raw producer gas involves the following steps: delivery of coal or coke to an overhead bunker; adjustment of rate of coal feed to maintain correct depth of fuel bed; stirring or levelling of fuel bed; removal of ashes and clinkers; adjustment of air to steam ratio; adjustment of supply of air and steam to maintain constant gas pressure; daily cleaning of producer (breaking clinkers from wall, during which time a poor gas is made); weekly burning out of flue between producer and furnace; putting air into instrument lines to keep tar out.

In spite of these troubles, raw producer gas is a fairly inexpensive fuel. Its cost can be computed from the following data: cost of coal, producer efficiency, and cost of gasification. Lump coal with a high temperature of ash fusion is preferred. Modern gas producers have an efficiency of 90 or even 95 per cent, referred to the hot gas.

The following figures on gasification cost are based on a producer installation operating at near its normal rating and gasifying fuel at the rates shown:

	Anthracite	Bituminous	Coke
Total fuel gasified per hr	2 tons	4 tons	3 tons
Gasification cost per net ton	\$1.85	\$1.00	\$1.11

The above figures do not include any administration, overhead, taxes, amortization, or similar charges. The costs are based on labor at \$2.00 per hour; for other labor rates the gasification cost will be almost in proportion to the hourly labor rate.

In *The Glass Industry*, March 1948, F. G. Schwalbe published a detailed study on the cost of gasification of bituminous coal. It is

TABLE III

PRODUCER PLANT-OPERATING COSTS

Number and size of producers	2 10-foot	1 10-foot	1 8-foot
Coal gasified per 24 hours	70.3 ton	41 ton	20.5 ton
Per cent of producer capacity	61.5%	71.9%	59.8%
Coal required to make steam per 24 hours	4.38 ton	2.70 ton	1.35 ton
Operating cost per week:			
Producer and boiler operators @ $1.25 per hour	$210.00	$210.00	$210.00
Dust removal @ $1.00 per hour	32.00	16.00	16.00
Coal and ash removal @ 10 cents per ton of coal	52.27	28.70	15.30
Burn-out every 6 days @ $1.00 per hour	8.00	8.00	8.00
Repair labor @ $1.65 per hour	13.20	6.60	6.60
Total labor per week	315.47	269.30	255.90
Total labor per ton of coal gasified	0.641	0.676	1.783
Power per week kw-hr @ 12 cents	28.80	14.40	13.20
Repair materials, including coal, machinery, producers, auxiliaries, boilers, painting, etc., estimated during life of plant per week	60.00	30.00	30.00
Boiler-feed water and producer-cooling water based on recirculating water, 190 gallons per ton of coal @ 10 cents per M gallon per week	9.35	5.45	2.73
Oil, waste, grease, supplies per week	6.00	3.00	3.00
Total cost of gasifying coal per ton, exclusive of coal	0.852	0.860	2.124
Cost of producer plant	$125,000.00	$95,000.00	$75,000.00
Depreciation at 10% per ton of coal gasified	0.488	0.635	1.005
Total cost per ton of gasified coal including depreciation	$1.340	$1.495	$3.129

here reprinted (with permission) as Table III. Since all labor rates are given, the cost of gasification can be computed at any time, as long as the prevailing wage rate is known.

Experiments have been made for the purpose of raising the heating value of raw producer gas by increasing the oxygen content of the blower air. Air containing 25 per cent oxygen raised the lower heating value from the original value of 160 Btu/cu ft to a new value of 184 Btu/cu ft. (*Industrial Heating*, June 1952, page 1058.)

Clean Producer Gas. Raw producer gas leaves the producer at a temperature between 1000 F and 1400 F; it cannot be transported

through long pipe lines without losing its sensible heat and having its tarry vapors condensed. If it is necessary to locate the producer plant at a great distance from the furnace or if many comparatively small and scattered furnaces are to be fed, the gas is cooled and cleaned. It is then known as cold or clean producer gas. Conversion of raw producer gas into clean producer gas requires a cooler, a tar extractor, a scrubber, and a gas exhauster (driven by engine or motor). Disposal of the tar is a serious problem, because the tar is too wet to burn. Clean producer gas can be transmitted over long distances through bare pipes. However, the low heating value (128 Btu/cu ft, lower value at 62 F) necessitates comparatively large pipes or else excessive power consumption, if the gas is to be transmitted several thousand feet. Clean gas can be stored in gas holders, a fact that makes its use desirable for fluctuating or intermittent demand.

Abstraction of tar and of sensible heat reduce the thermal efficiency of the cold-gas process to about 70 per cent, unless the sensible heat of the gas is utilized for the generation of steam. The cost of gasification is also higher than that of raw gas, because the equipment is more expensive and because more apparatus has to be tended.

Clean gas always burns with a clear, non-luminous heat, even if the gas is preheated in recuperators or regenerators.

In the 1920's, clean producer gas was considered to be the most suitable fuel for scattered furnaces in an industrial establishment. It has largely been replaced by natural gas and by electrical energy in the United States.

Blast-Furnace Gas. This gas is given off at the top of blast furnaces (for making pig iron); it is available for heating furnaces in combined blast-furnace and steel plants only. The fuel practice in many American steel works is so wasteful that no excess gas is left for use in heating furnaces. In modern or modernized works, economy of blast stoves and of blowing equipment has been improved to such an extent that surplus gas is available. Fuel economy at the stoves and in the blowing department can be attained by well-cleaned gas only; the surplus gas going to pit furnaces and other heating furnaces is, therefore, a thoroughly clean gas. Gas holders are not used. Excess gas is burned in a torch.

Blast-furnace gas is often mixed with by-product coke-oven gas. The mixture is called mixed gas.

Blast-furnace gas is extremely poisonous. Its heating value is so low that not only the air but also the fuel is highly preheated if furnace temperatures of 2200 F or higher are to be attained.

TABLE IV

PROPERTIES OF COMMERCIAL LIQUEFIED PETROLEUM GASES*

	Commercial Propane	Propane-Butane Mixture	Commercial Butane
Composition of Products			
Per cent ethane	2.50	0.75	
Per cent propane	96.00	28.80	20.00
Per cent isobutane	1.50	21.45	
Per cent normal butane		49.00	80.00
Specific gravity of liquid (60°/60° F)	0.507	0.556	0.569
Weight per gallon of liquid at 60° F, lb	4.23	4.63	4.74
Cu ft of gas at 60° F, 30″ Hg per gallon of liquid at 60° F	36.46	33.11	32.81
Specific volume of gas, cu ft/lb at 60° F, 30″ Hg	8.66	7.15	6.93
Specific gravity of gas (air = 1) at 60 ° F, 30″ Hg	1.520	1.843	1.907
Ignition temperature in air, °F	950–1,080	910–1,040	905–1,035
Calculated maximum flame temperature in air, °F	3,620	3,625	3,630
Maximum rate of flame propagation, AGA method, inches per second	11.4	12.0	12.0
Required for complete combustion			
Cu ft air/cu ft gas	23.76	28.62	29.47
Lb, air/lb gas	15.39	15.24	15.22
Products of complete combustion			
Cu ft CO_2/cu ft gas	2.99	3.66	3.78
Cu ft H_2O/cu ft gas	3.99	4.66	4.78
Cu ft N_2/cu ft gas	18.79	22.62	23.29
Lb CO_2/lb gas	2.99	3.02	3.02
Lb H_2O/lb gas	1.72	1.60	1.56
Lb N_2/lb gas	11.76	11.64	11.63
Ultimate CO_2 % by volume	13.71	13.94	13.97
Latent heat of vaporization at boiling point			
Btu per pound	184	169	170
Btu per gallon	775	784	805
High heating value (after vaporization), dry basis at 60° F, 30″ Hg			
Btu per cubic foot	2,510	3,014	3,112
Btu per pound	21,796	21,426	21,403

* Calculations based on Natural Gasoline Association of America data.

Liquefied Petroleum Gases (L.P.G.). These fuels are hydrocarbons within the range from C_3H_8 (propane) to C_4H_{10} (butane). They are gases or vapors at room temperature and atmospheric pressure, but are liquid at room temperature and high pressure. They are

compressed, cooled, and put into pressure vessels in which they are shipped as liquids. The commercial L.P. gases are extracted from refinery gas. They are mixtures of gases that have different compositions, as shown in Table IV.

Liquefied petroleum gases are shipped in strong tanks either by rail or in trucks. The standard capacity of railroad tanks is 10,000 gallons. There is no standard capacity for truck tanks, because different states impose different weight limits on trucks. In consequence, the capacity of truck tanks ranges between 2500 and 5000 gallons. For retail trade, L.P. gases are sold in steel bottles of 60 pounds or 100 pounds capacity.

The sales price of L.P.G. varies widely with time and with distance from oil wells and refineries. It rose from 2.5 cents per gallon in 1945 to 4 cents per gallon in 1952. These prices refer to tank-car lots F.O.B., Tulsa, Oklahoma. During 1948 the price rose temporarily to 6 cents per gallon. The effect of distance is illustrated by the following figures, which refer to 1952: 4 cents per gallon in Tulsa, 5¾ cents per gallon in Doeren, Kentucky, and 8½ cents per gallon in Newark, New Jersey.

L.P.G. are often used as stand-by fuel to serve during periods of shortage of natural gas. Propane is popular for this purpose. The gas is usually mixed with a small quantity of air for the purpose of bringing the heating value of the mixture down to that of natural gas and adapting the requirement for combustion air to that of natural gas.

During the second world war, several heat-treating furnaces were fired with butane.

Additional information on L.P.G. is contained in the handbook "Butane and Propane Gases," Jenkins Publications, Los Angeles 14, California.

Casing-Head Gasoline. Before natural gas is sent into pipe lines, it is compressed and cooled. The condensate bears the name casing-head gasoline. Its composition varies widely with the location of the gas wells. This fuel is an excellent substitute for natural gas on very cold days, when natural gas is shut off. However, there is so little of it that it is not generally available.

Reformed Gases. Natural gas and refinery gas have been "reformed" for the purpose of reducing their calorific value so that they may be sent into burners that were designed for city gas. To this end, the rich gases are either mixed with some air or else they are partly burned in an atmosphere of air and steam. The use of reformed gas in industrial furnaces is very rare indeed.

Oil Gas and Oil Vapor. Before the general distribution of natural gas, considerable quantities of oil gas were produced along the Pacific coast, by a process which somewhat resembles the carburetion of blue water gas. The gas contains about 11 per cent CO, 27 per cent CH_4, and 53 per cent H_2, plus some illuminants. The high and low heating values are 520 and 462 Btu per cu ft. The composition varies with the kind of oil used and the operation of the generator. Oil gas is a true gas.

Light oils such as kerosene or No. 1 fuel oil are occasionally burned in vapor form; the vapors pass through gas burners and not through oil burners. The light oils are vaporized by the application of heat, as shown in Fig. 11. A small oil flame burns down into the center pipe. The products of combustion are cooled by the tube wall and bubble through kerosene at the bottom. The rising oil vapors are superheated by the tube wall and, in passing out of the vaporizer, are mixed with air in control equipment. When kerosene is being vaporized, the vapor generator must be cleaned every two weeks because cracking of the oil vapors cannot be entirely eliminated. If heavier oil is vaporized, the generator is choked up very quickly.

The oil vapors condense if cooled below the saturation temperature. For that reason, the vapor-carrying pipes are insulated. Even with this precaution, the vapor is carried not more than 60 feet from the generator. A steam-filled copper pipe in the center of the oil-vapor pipe permits a considerably greater distance between generator and furnace. In the United States, the vaporizer bears the name "Vapofier."

Liquid Fuels

The liquid fuels which are commonly used for industrial furnaces are fuel oil and tar. Gasoline, kerosene, and alcohol are too expensive to be considered for industrial heating purposes, except for very small furnaces and as stand-by fuels during a few very cold days, when natural gas is diverted to domestic consumers.

Liquid fuels offer a number of advantages. A liquid can readily be stored above or below ground and in out-of-the-way places. Some of the liquid fuels need no preheating and are always ready to serve, like natural gas or city gas, with the additional advantage that, while natural gas is frequently shut off in cold weather, liquid fuel can be drawn from storage in the coldest of weather. With liquid fuel, there are none of the stand-by losses which are inevitable with gas producers, water-gas plants, or any other equipment for the generation of

an industrial gas. Control of furnace temperature and of furnace atmosphere are not affected by events beyond the control of the operator, such as occur in the gas-making processes. Liquid fuels are easily transported from storage place to furnace and burn without leaving a noticeable residue of ash.

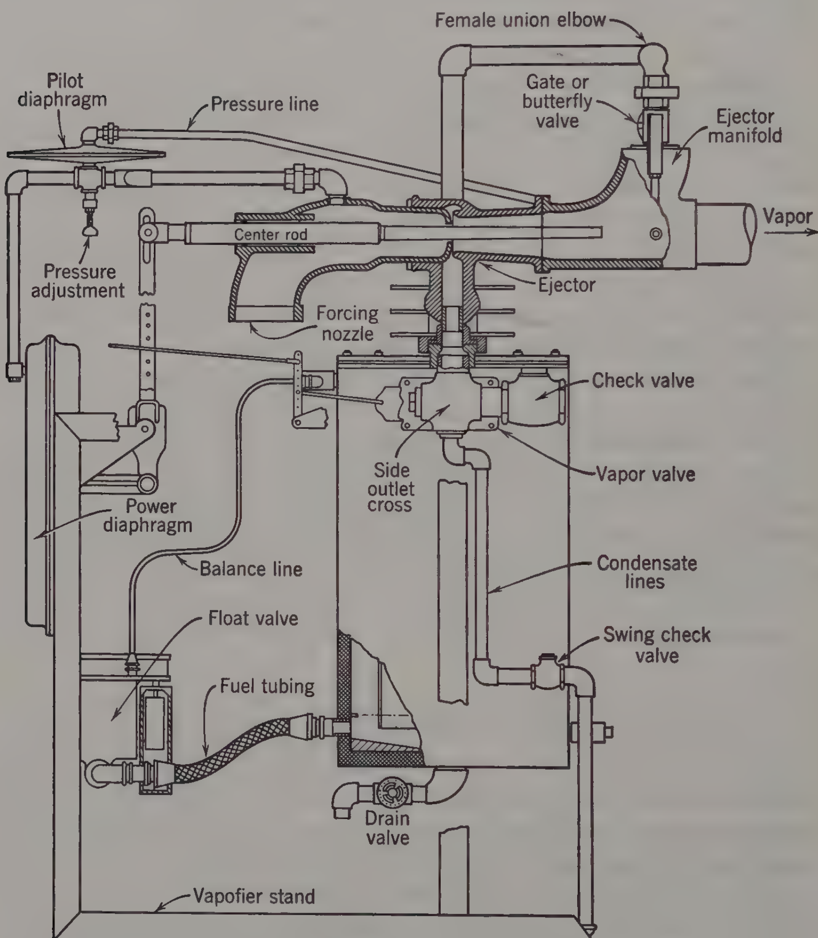


Fig. 11. Vaporizer for light oil. Courtesy of the Vapofier Co.

Liquid fuels vary in viscosity, depending upon their composition and temperature. Some of the fuels can be pumped and burned without preheating, while others need preheating. The equipment necessary for a complete installation will consequently depend upon the quality of the fuel which is to be burned.

Fuel Oil. Fuel oils are hydrocarbons which are left after the lighter and more volatile products such as gasoline, naphtha, and kerosene have been removed from the crude oil. In consequence, fuel oil for combustion in industrial furnaces denotes any oil that is heavier than kerosene. It may be a distillate (gas oil, Diesel oil)

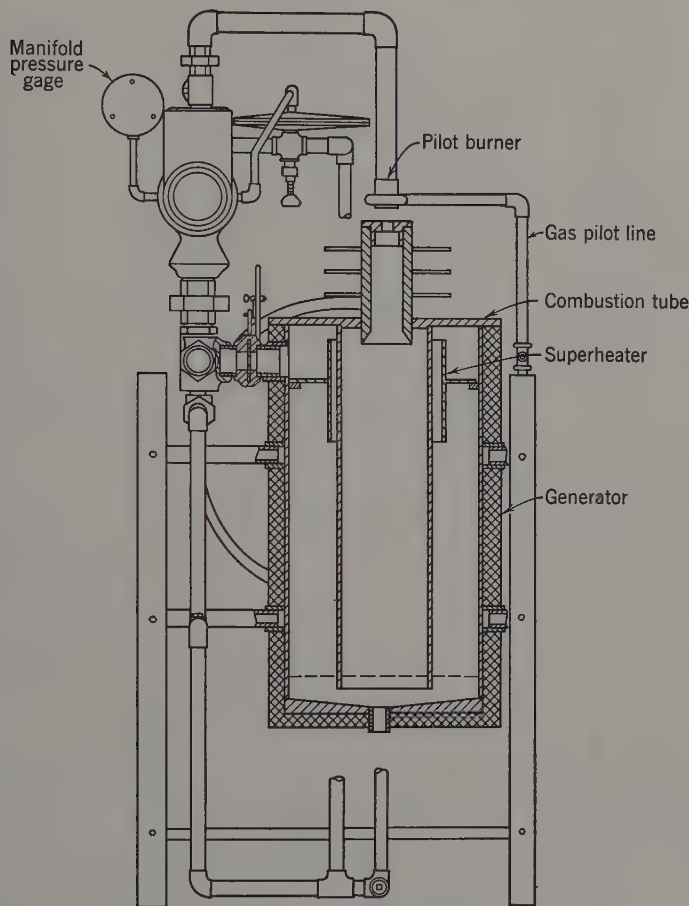


FIG. 11 (*Continued*)

which either leaves the still after kerosene has passed over or else is taken from a lower section of the fractionator. Most of the heavy fuel oil is a residue from distillation or cracking processes.

Fuel oils are classified and standardized. Originally, six grades were recognized; later on, No. 4 was dropped. In the classification adopted in 1948, No. 4 was reinstated and No. 3 was dropped. Some

TABLE V

Detailed Requirements for Fuel Oils*

Grade of Fuel Oil†		Flash Point, °F	Pour Point, °F	Water and Sediment, %	Carbon Residue on 10% Residuum, %	Ash, %	Distillation Temperatures, °F			Viscosity								Gravity, °API
										Saybolt				Kinematic Centistokes at				
Number	Description						10% Point	90% Point	End Point	Universal at 100° F		Furol at 122° F		100° F		122° F		
		min.	max.	max.	max.	max.	max.	max.	max.	max.	min.	max.	min.	max.	min.	max.	min.	min.
1	Distillate oil intended for vaporizing pot-type burners and other burners requiring this grade.‡	100 or legal	0	Trace	0.15	—	420	—	625	—	—	—	—	2.2	1.4	—	—	35
2	Distillate oil for general-purpose domestic heating for use in burners not requiring No. 1.	100 or legal	§20	0.10	0.35	—	‖	675	—	40	—	—	—	(4.3)	—	—	—	26
4	Oil for burner installations not equipped with preheating facilities.	130 or legal	20	0.50	—	0.10	—	—	—	125	45	—	—	(26.4)	(5.8)	—	—	—
5	Residual-type oil for burner installations equipped with preheating facilities.	130 or legal	—	1.00	—	0.10	—	—	—	—	150	40	—	—	(32.1)	(81)	—	—
6	Oil for use in burners equipped with preheaters permitting a high-viscosity fuel.	150 or legal	—	¶2.00	—	—	—	—	—	—	—	300	45	—	—	(638)	(92)	—

* Recognizing the necessity for low-sulphur fuel oils used in connection with heat treatment, non-ferrous metal, glass, and ceramic furnaces, and other special uses, a sulfur requirement may be specified in accordance with the following table:

Grade of Fuel Oil	Sulfur, max. per cent
No. 1	0.5
No. 2	1.0
Nos. 4, 5, and 6	No limit

Other sulfur limits may be specified only by mutual agreement between the buyer and seller.

† It is the intent of these classifications that failure to meet any requirement of a given grade does not automatically place an oil in the next lower grade unless in fact it meets all requirements of the lower grade.

‡ No. 1 oil shall be tested for corrosion for 3 hours at 122° F. The exposed copper strip shall show no gray or black deposit.

§ Lower or higher pour points may be specified whenever required by conditions of storage or use. However, these specifications shall not require a pour point lower than 0° F under any conditions.

‖ The 10 per cent point may be specified at 440° F. Maximum for use in other than atomizing burners.

¶ The amount of water by distillation plus the sediment by extraction shall not exceed 2.00 per cent. The amount of sediment by extraction shall not exceed 0.50 per cent. A deduction in quantity shall be made for all water and sediment in excess of 1.0 per cent.

users of fuel oil even now order No. 3. The 1948 classification is laid down in "Fuel Oils, Commercial Standard CS12-48," 6th edition, published by the U. S. Department of Commerce. Table V was taken from page 2 of that publication.

TABLE VI

TYPICAL PROPERTIES OF FUEL OILS

	Kerosene or No. 1	Light Distillate or No. 2	No. 4 Fuel Oil	No. 5 Fuel Oil	No. 6 Fuel Oil
Identifying properties					
Type of oil	Distillate	Distillate	Very light Residual	Light Residual	Residual
Color	Light	Amber	Black	Black	Black
Gravity, °API	40	32	21	17	12
Carbon residue	Trace	Trace	2.5%	5.0%	12.0%
Pumping and atomization properties					
Viscosity, Centistokes/ 100° F	1.6	2.6	15.0	50.0	700.0
Pour point	Below 0° F	Below 0° F	10° F	30° F	65° F
Preheat temperature required					
For pumping	Atmospheric	Atmospheric	At least 15° F	At least 35° F	100° F
For atomizing	Atmospheric	Atmospheric	At least 25° F	130° F	200° F
Purity					
Sulfur content	0.1%	0.4%*–0.7%	0.4%*–1.5%	2.0% max.	2.8% max.
Sediment and water	Trace	Trace	0.5% max.	1.0% max.	2.0% max.
Ash content	Trace	Trace	0.02	0.05%	0.08%
Composition					
Oxygen and nitrogen	0.2	0.2	0.48	0.70	0.92
Hydrogen	13.2	12.7	11.90	11.70	10.50
Carbon	86.5	86.4	86.10	85.55	85.70
Heat content					
Btu per gallon	137,000	141,000	146,000	148,000	150,000

* The lower sulfur quality is available as a special product.

In Table V the density[1] (API gravity) is given for No. 1 and No. 2 oils only; and, furthermore, that table does not contain other information that is of interest to the user. For these reasons, Table VI is offered. It was furnished by the Standard Oil Development Company.

For many years, specific gravity played an important part (and to some extent it still does) in the designation of a fuel oil for this

[1] The density or "gravity" of oil is expressed in any of three ways: as specific gravity, in degrees Baumé, or in degrees API (American Petroleum Institute). In each designation the density of oil at 60 F is compared to the density of water at the same temperature. The three designations are related by the following equations:

$$\text{Specific gravity} = \frac{141.5}{\text{API} + 131.5} = \frac{140}{\text{Baumé} + 130}$$

The difference between the two scales is extremely small.

reason: The viscosity of the oil (which determines the nature of the heating apparatus required for its pumping and atomization) varies with the density, the light oils being more fluid at room temperature than the heavy ones. However, there is no definite connection between density and viscosity; oils of the same density, but of different origin, frequently have different viscosities. Although the

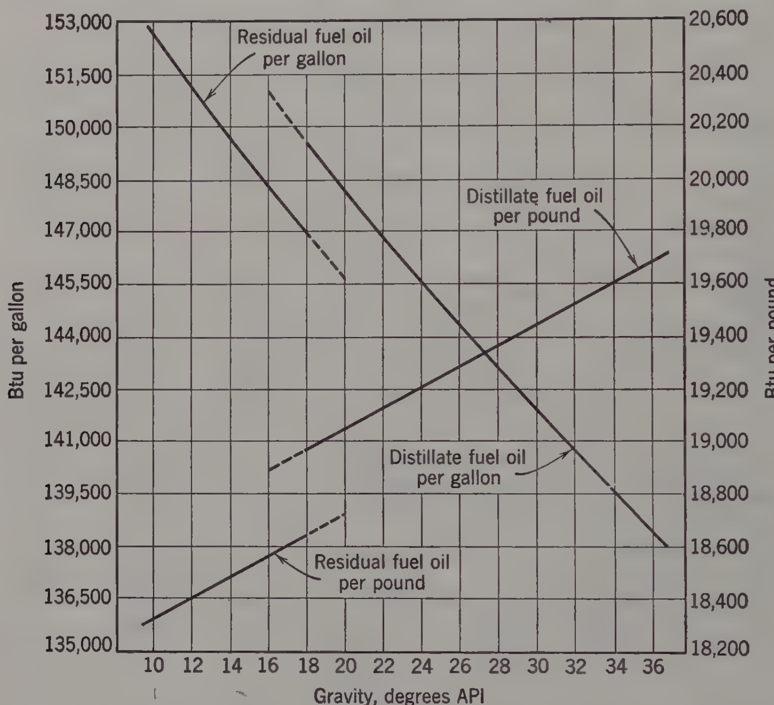


Fig. 12. Approximate relation between gravity API and Btu per gallon.

latter property is of great importance for the combustion of oil, it is not readily measured, requiring a delicate instrument and, frequently, much time for its determination. On the other hand the degrees API or Baumé (which express the specific gravity) can be easily and quickly measured with a hydrometer. This fact, coupled with the general, although indeterminate, relation between viscosity and specific gravity, has given rise to the custom of describing an oil by its density rather than by its viscosity.

The relation between gravity of oil and calorific value is given in Fig. 12. This chart exhibits the fact that the light oils have a high heating value per unit weight, although they have a low heating value per unit volume.

The viscosity of oil at various temperatures is of importance not only for the design of burners but also for the design of valves and pipe lines. Average values may be taken from Fig. 13, which is patterned after an ASTM chart. In reality, each line should be replaced by a broad band. This statement is especially true for Nos. 4, 5, and 6.

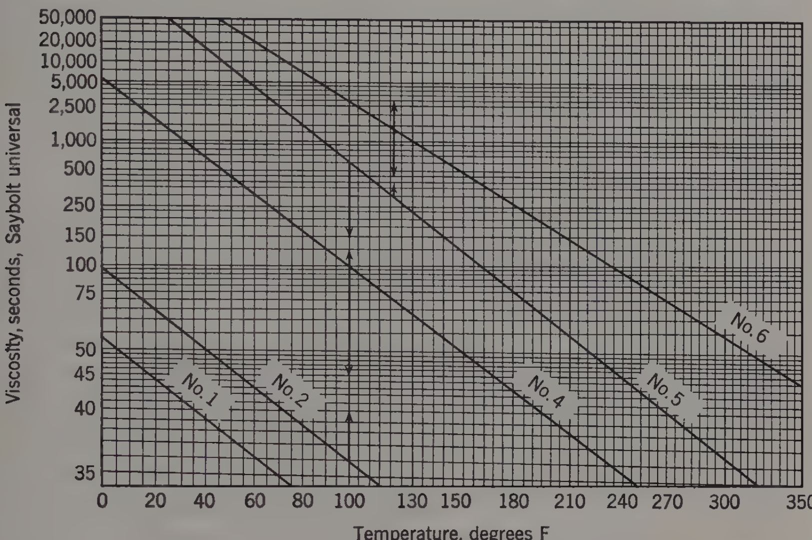


FIG. 13. Typical temperature-viscosity relations for fuel oils. Arrows indicate the maximum and minimum limits established by the U. S. Bureau of Standards for each grade of oil.

Fuel oil must be strained before entering a control valve or a burner. Even the distillate oils contain solid particles; they are disintegrated packing material coming from the pumps.

Oil is sold by volume rather than by weight, the units being the U. S. gallon and the barrel of 42 gallons. Since the volume of a given weight of oil varies considerably with the temperature, weight deductions from the volume must be based on a definite temperature, which is usually 60 F. In the checking of quantities of oil in storage tanks, the temperature must be taken into consideration.

The cost of oil is expressed either in cents per gallon or in dollars per barrel. As a rule, but not always, the price of light fuel oils is higher than that of heavy residual oils. At one time, oils of both types commanded the same price. The price of fuel oil fluctuates erratically. The following figures for the price of heavy fuel oil in the Chicago district (ASME, 1951) confirm this statement:

Year	1945	1946	1947	1948	1949	1950
Dollars per barrel	1.60	1.87	2.34	3.00	2.28	2.54

Oil is shipped in tankers, barges, railroad tanks, and in truck tanks. The delivered price varies greatly with method of transportation and with distance.

Coal Tar. Raw coal tar is one of the products of the destructive distillation of bituminous coal carried out at high temperature. A typical composition of tar follows: carbon, 86.7 per cent; hydrogen,

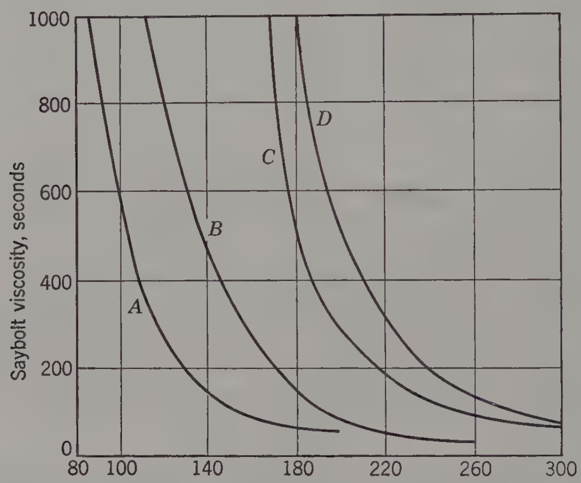


FIG. 14. Temperature-viscosity relation for tar and pitch. *A* and *B* refer to raw tar made in two different coking plants; *C* refers to topped tar; *D* refers to a mixture of tar and pitch.

6.0 per cent; nitrogen, 0.1 per cent; sulphur, 0.8 per cent; oxygen, 3.1 per cent; ash, 0.1 per cent; water, 3.2 per cent. The black color is due to free carbon in suspension (about 4 per cent). The high heating value equals 16,340 Btu per lb. Raw tar weighs 9.5 lb per gal. It will be seen from the above analysis that raw tar has almost the same chemical composition as the combustible matter of the coal from which it is made.

The relation between the temperature of raw tar and its viscosity is indicated by Fig. 14. The curves *A* and *B* represent lower and upper limits. Even though the source of tar does not change, its viscosity varies with coal chemistry and moisture. Tar is very viscous when cold, and must be preheated before it can be pumped through pipe lines. It is not advisable to increase the temperature of raw tar to more than 165 F or 170 F at the maximum, for several

reasons. It contains volatile constituents, which evaporate and cause irregular operation of the burners and have a low flash point so that there would be danger of fire if leaks appear in the pipe lines. If tar is kept at a temperature of 200 F (or above) for some time, a hard residue which is mostly coke settles at the bottom of the tank.

The volatile constituents of raw tar (the tar acids) are in demand by the chemical industry and are usually distilled off before the residue is burned. This residue is known as topped tar or, as tar pitch, or as pitch tar if the distillation is more complete. There is no standard composition for pitch tar. Under average conditions carbon is almost 90 per cent, while hydrogen is reduced to approximately 5 per cent. Not all pitch serves as fuel; a large portion is used in building roads. The variety of uses has resulted in classifying pitch not by composition but by softening temperature. A consequence of the range of composition of topped tar is a similar range in viscosity; this range is demonstrated by Fig. 14 previously referred to.

In the practice of burning pitch, one part of pitch is usually mixed with two parts of raw tar or with two parts of a special oil that does not separate from the pitch. The mixture is heated to 220 F.

Tar Oil. In low-temperature distillation of coal, a light-colored oil is obtained which has been given the name "tar oil." It is the starting point for many light liquids, such as benzol, toluol, and others. It forms an excellent fuel for Diesel engines, and can be burned like fuel oil in industrial furnaces. At the present time, the output of tar oil in the United States is so small that it can scarcely be considered as a fuel for industrial furnaces. This condition will doubtless be changed in the future, and when this occurs it will be advisable to investigate the properties of this fuel more carefully.

Solid Fuels

Coal (including lignite), coke, petroleum coke, wood, charcoal, and peat are the solid fuels which are in use in various parts of the world. Wood, charcoal, and peat serve as fuel for industrial furnaces so seldom that they need not be discussed here.

Solid fuels, unless used in powdered form, cause some inconvenience in transportation to the furnace and have the additional disadvantage of leaving ashes and clinkers which must be removed from time to time.

The combustion of solid fuel on a grate cannot be as well controlled as that of gaseous or liquid fuels. If solid fuel is finely powdered, the

control of the combustion approaches in effectiveness that of the previously described fuels, without, however, reaching it.

Coal. Coal is, without any doubt, the most important industrial fuel in the world. Many other fuels such as coke, tar, coke-oven gas, benzol, motor fuel (by hydrogenation), retort gas, water gas, producer gas, and blast-furnace gas are derived from it. "Coal" is a collective term for a wide variety of fuels, with different properties and different heating values.

Fig. 15 gives a faint conception of this variety and, incidentally, explains the relation between composition, heating value of ash-free coal, and name. In practice, still greater variation is introduced by the difference in the ash content and the composition of the ash.

It is impossible to predict all the properties of a coal from the proximate analysis represented by Fig. 15. The chances of predicting the properties from an ultimate analysis are somewhat better, but the prediction is by no means infallible because the hydrocarbons exist in the coal in different combinations. As definite methods of predicting the properties of a brand of coal do not exist at the present time, trial and experimentation are necessary.

The bituminous coals are the most important ones for industrial furnaces as well as for coking and for gasification. Anthracite (if and where available) is used for making water gas and clean producer gas.

The behavior of coal on the grate, in the coke oven, and in the gas producer depends to a very large extent upon its coking or caking properties, as well as upon its chemical composition, and also upon the composition of the ash. In the United States no generally accepted simple classification exists from which these properties can be predicted.

Caking coals are those which fuse and swell in size when heated; non-caking coals burn without fusing. In general, the high-volatile coking and gas coals are caking coals, while the low-volatile or semibituminous coals are non-caking. Although the rule is not infallible, it appears that those coals are caking for which the ratio of oxygen to hydrogen lies within the limits of 1.0 and 2.0 approximately. But in spite of different scientific tests on agglutination, etc., the old rule survives: "Buy a carload and try it."

The quantity and composition of the ash in the coal have great influence upon the quality and the usefulness of the coal for specific purposes. Those properties of the ash which are of greatest importance are its fusibility and the viscosity-temperature relation of the molten ash. When trouble arises, it is advisable to send coal samples to a testing laboratory (the United States Bureau of Mines, Pitts-

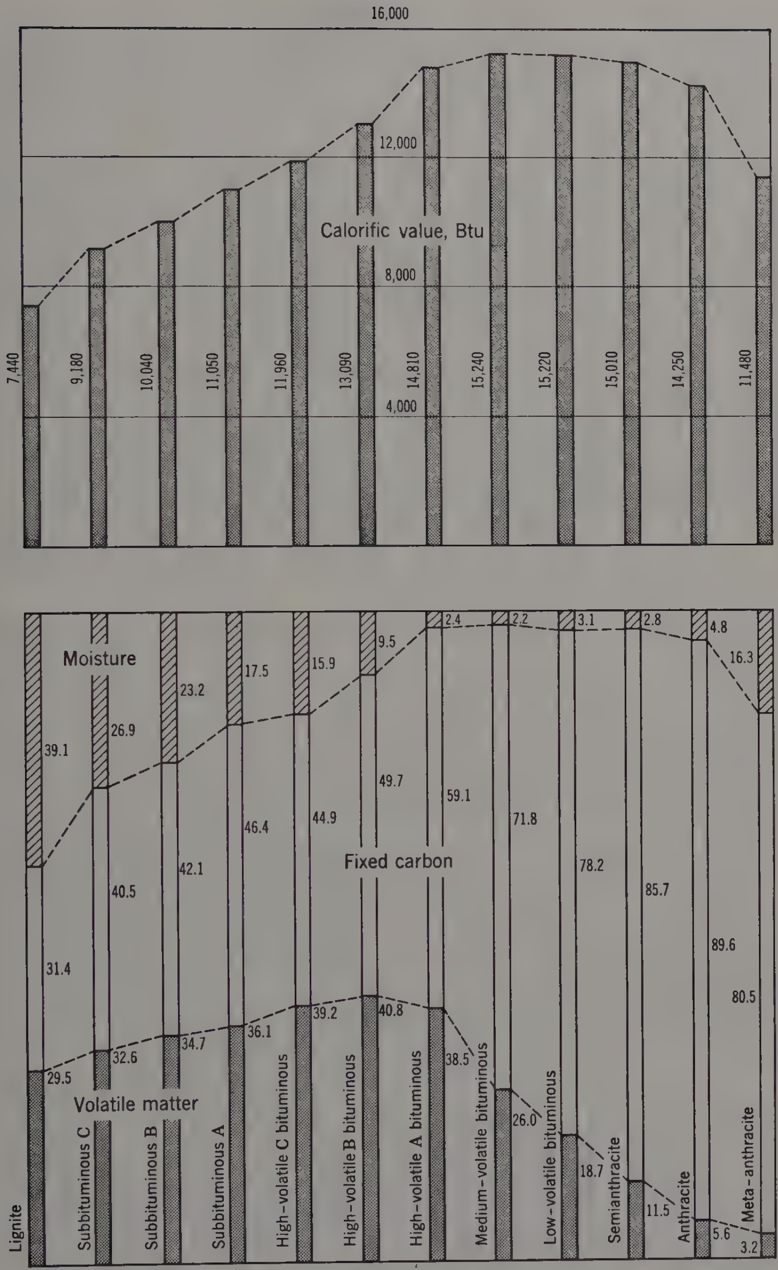


FIG. 15. Composition and heating value of various kinds of coal. Prepared by W. A. Selvig, U. S. Bureau of Mines. The calorific value refers to 1 lb of ash-free coal.

burgh 13, Pennsylvania, will furnish addresses of coal-testing laboratories) and to have the fusing point determined by test. Endless annoyances with gas producers, coal grates, or powdered-coal furnaces can be prevented by regular testing of samples of coal to be delivered.

The brown coals, or lignites, contain a great deal of moisture and are unsuited for use in industrial furnaces unless the moisture is first driven off by an inexpensive process. Dried brown coals are very hygroscopic; that is to say, after having been dried, they readily reabsorb moisture from the atmosphere. This fact should be kept in mind by all persons who use them for industrial furnaces. After drying, lignites are very suitable for burning in industrial furnaces.

On the basis of heat units developed per unit of cost, coal is without any doubt the cheapest fuel; but there are many other considerations which make the use of solid coal undesirable for most industrial heating operations. These considerations are dealt with in Chapter VI.

The solid coal weighs 75 to 110 lb per cu ft, its specific gravity being 1.2 to 1.8. Coal as shipped weighs 53 lb per cu ft (average). A bushel of coal contains 70 to 76 lb.

Run-of-mine is bituminous coal as broken in the mine, not having been screened. It contains both large lumps and fine coal. *Lump coal* is that which will not pass through a bar screen with openings 1¼-in. square. *Nut coal* passes through a screen with 1¼-in. openings, but not through one with ¾-in. openings. *Slack coal* passes through the ¾-in. openings of the screen.

The cost of coal *fluctuates* but little; it *rises!* In 1900, bituminous coal in barges, floating down the Monongahela river, could be bought for 65 cents per ton; the cost had risen to $6.80 in 1952. This rise is equivalent to an increase (in any one year) of 4½ per cent over the preceding year. Since 1939, the yearly increase has been higher, somewhere between 5½ and 6 per cent.

Powdered Coal. As the name implies, powdered coal (also called pulverized coal, and sometimes called comminuted fuel) is coal which has been reduced to a fine powder. With lump coal and slack coal, it shares the fate of being used but little for industrial furnaces in the United States. For most industrial furnaces, its use is undesirable and is confined to emergency situations, when and where more desirable fuels are not available. In countries with very little oil or natural gas, coal is an important fuel for industrial furnaces. In a small country such as West Germany, more than 40 furnaces are fired with powdered coal. Powdered coal has some characteristic properties of its own which must be briefly discussed.

Fineness. The size of the coarsest particles in the powder determines the length of the combustion space, unless unburned fuel particles are permitted to escape. For that reason, fineness is of importance and must be measured. In practice fineness is judged by the fraction which passes through certain standard sieves, the dimensions of which are given in Table VII. The most commonly accepted standard for fineness is the fraction that passes through a sieve with 200 meshes to the inch. The minimum recommended fraction for large steam generators is 65 to 85 per cent, depending upon the size of the boiler. For industrial furnaces, 90 to 95 per cent are recommended. With

TABLE VII

Meshes to the Linear Inch	United States Standard		British Standard	
	Diameter of Wire, in.	Size of Opening, in.	Diameter of Wire, in.	Size of Opening, in.
60	0.0064	0.0098	0.0083	0.0083
100	0.0042	0.0058	0.0050	0.0050
200	0.0021	0.0029	0.0025	0.0025
323	0.0014	0.0017		

this fineness of the coal powder, most of the ash floats in the flame and is carried out of the furnace. The finer the ash, the less it bothers the neighbors, because fine ash is blown a long distance by the wind; especially, if the stack is tall.

Moisture. A second characteristic which affects the usefulness of powdered coal is the amount of moisture it contains. Coal can be powdered with moisture up to 7 per cent, but the energy consumption is much greater in the powdering of wet coal than it is for dry coal. Moisture has a great influence in the feeding and combustion of powdered coal. On account of the close relations between these factors, detailed discussion of the effects of moisture is postponed to the next chapter.

Ash. A third characteristic of powdered coal is furnished by its ash, with regard to content, composition, and fusion point. The lower the ash content, the smaller are the chances of trouble arising from the ash. The fusion temperature is important for the following reason: The adiabatic flame temperature of coal is so high, that any known coal ash melts several hundred degrees below that temperature. If the ash has a very high fusion temperature, the fraction that melts (because of being in the hottest part of the flame) is small, especially

if the shape of the combustion space is such that the heat of the flame can radiate away freely. In such a case the furnace is said to work with a dry ash. But if the fusion point of the ash is low, almost all of the ash is melted into tiny drops which attract one another and become bigger drops or pellets. Some of the drops become so heavy that they no longer float in the flame. They are deposited on the hearth, on the charge, and sometimes on the lower part of the side walls. If a flame containing low-melting ash is directed along the roof of the furnace, the wet ash adheres to the roof and to itself, forming whiskers.

Nevertheless, some furnaces operate successfully with a wet ash. The author made the following observations: In one rolling mill, a coating or layer of wet ash stuck to the billets as they left the furnace. In this old-fashioned three-high mill, the wet ash was chilled by the rolls; it was cracked and flung off the rolls by centrifugal force. The first pass looked like a Fourth-of-July pinwheel. The finished steel was clean and free from streaks or spots. A second mill observed by the author was a continuous mill. The first stand of such a mill always rotates at a very low angular velocity. The ash was not thrown off but was rolled into the steel, causing streaks and spots. In the first (old-fashioned) mill, the furnace is being fired with powdered coal today. In the second (modern) mill, the operators were glad when another fuel was piped into the mill.

If the furnace temperature is 1600 F or lower, the combustion space can be so designed that the ash is dry even when it has a low fusion temperature.

Tables with information on various coals, including fusion temperature of ash, were published by the United States Bureau of Mines. They have found their way into most handbooks on mechanical engineering.

Cost of Powdered Coal. The cost of powdered coal at the furnace is the sum of many items, the principal items being the following:

1. Cost of raw coal.
2. Size of delivered coal.
3. Grindability of coal.
4. Moisture in coal.
5. Cost of pulverizing plant.
6. Cost of operating labor.
7. Maintenance.
8. Type of pulverizing equipment.
9. Capacity of pulverizers.
10. Per cent of capacity used.

Most of these cost items go up with the cost of labor. They add up to the conclusion that the cost of coal preparation per unit weight (for instance, per ton) of coal equals one quarter of the cost of the raw coal, if the grindability[2] is high and if medium fineness is expected. It may reach 30 per cent of the cost of the raw coal, if the grindability is low, if the ash content is high, and if a high degree of fineness is required.

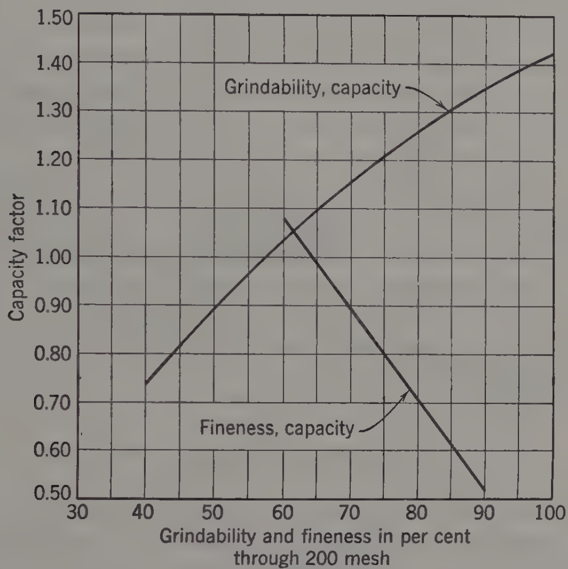


FIG. 16. Typical variation of pulverizer capacity with fineness and grindability. Based on capacity factor 1.00 for Pittsburgh coal and fineness of 65 per cent through 200 mesh. Courtesy of Babcock and Wilcox Co.

The effects of grindability and of required fineness upon capacity of pulverizer (and upon cost) are elucidated by Fig. 16. If *one* pulverizer suffices for a fineness of 65 per cent through a 200-mesh sieve, *two* pulverizers of the same size are needed for a fineness of 90 per cent. The relations that are indicated in Fig. 16 vary somewhat with the type of pulverizer.

The cost ratios of 25 and 30 per cent are correct for average conditions. For very small daily capacities the percentage is much higher than it is for standard conditions. Experience has taught that it is not advisable to pulverize less than 2 tons of coal per hour.

[2] For definition and values of grindability see, for instance, Kent's "Mechanical Engineers' Handbook," Power Volume, Section 7, article entitled Pulverizers and Pulverized Coal, John Wiley & Sons, 1950.

Coke. In the United States coke is seldom used directly in industrial furnaces because gaseous and liquid fuels are available at comparatively low cost. Indirectly, large quantities are used in the making of clean producer gas, blast-furnace gas, and blue water gas. In Europe coke is quite commonly used in industrial furnaces.

A bushel of coke weighs about 40 lb. A cubic foot contains 22 to 27 lb. The true specific gravity of the coke material is 1.5 to 1.8; the apparent specific gravity of a solid piece of coke is 0.8 to 1.0.

The moisture content of coke (quenched) varies from ¼ per cent to 11 per cent, average 8 per cent. The ash content is 10 to 14 per cent. Cost (at Pittsburgh, 1953) was $17 per ton. Small-sized coke (coke braize) in some localities can be obtained very cheaply because it contains much ash and sulphur.

Petroleum Coke. During the early years in the history of petroleum cracking, petroleum coke was an unwelcome by-product which the refineries tried to sell by recommending its use for combustion purposes. In the meantime, so many other industrial uses have been found for this material that it is no longer available for furnace use. For that reason, information on composition and on cost would serve no useful purpose.

Electrical Energy

Ironically, coal, the direct use of which is becoming smaller and smaller in industrial furnaces, has found an ever-increasing indirect use over the detour of combustion in steam generators and conversion of steam energy into mechanical and electrical energy. Industrially, electricity is a very convenient way of transmitting energy over appreciable and even long distances. It converts itself into heat spontaneously, and such conversion is easily controlled.

Electrical energy is sold by the kilowatt-hour, which equals 3413 Btu. The sales price of a kilowatt-hour (kw-hr) depends upon many circumstances such as the cost of fuel at the generating station, construction cost of the power plant, size and efficiency of the prime movers, rate of power consumption, distance from generating station, and the ratio of maximum demand to average demand. While it seems hopeless to derive an equation or to construct a set of curves that faithfully represents all of the above-mentioned influences, the nest of curves shown in Fig. 17 contains enough information to impart a sense of values. Electrical energy is not expensive, if the load factor is high. For that reason, it is usually advisable to sacrifice the speed of heating up the furnace (which would place a heavy demand on

transformers, transmission line, and generating station) to a lower energy rate. As a rule, excess-demand rates cost more than an extra hour of overtime wages.

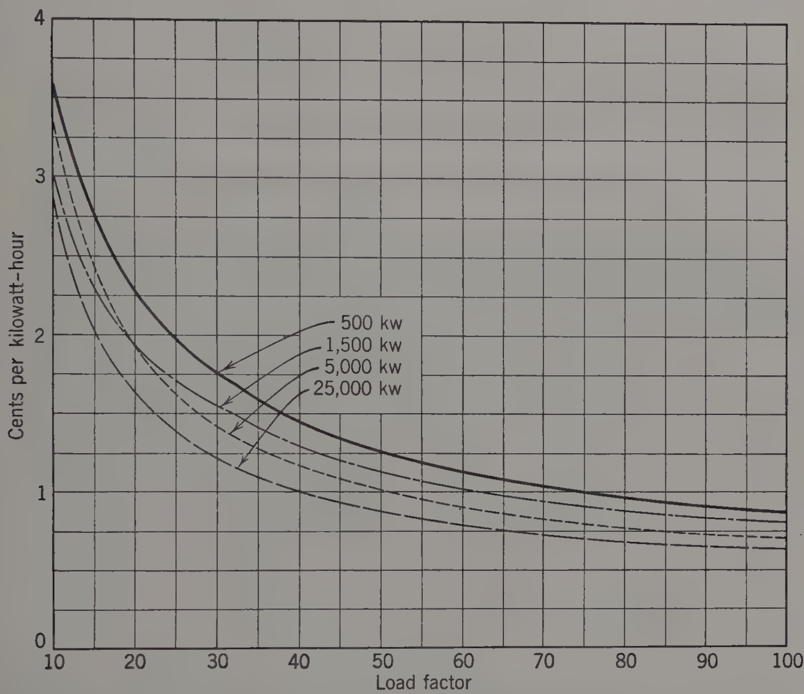


FIG. 17. Cost of a kilowatt-hour related to load factor, for various kilowatt loads. 25,000 volts service; 100 per cent power factor; coal cost 17½ cents per million Btu. Courtesy of West Penn Power Co.

Lower rates than those indicated in Fig. 17 are encountered if the power is generated in hydraulic power plants that were built years ago, when the cost of construction labor was a fraction of the present rates.

CHAPTER II

COMBUSTION DEVICES AND HEATING ELEMENTS

General Notes on Combustion Devices

In well-designed furnaces the combustion device (or heat-liberating device) and the furnace (and often also the material being heated) are properly adapted to each other and form an integral combination which both generates and utilizes heat. It is usually quite difficult to draw the line where heat generation stops; the heat generation is begun in the combustion device and should be finished in the furnace. For that reason, it may seem illogical to study "combustion devices," or "burners," separately. On the other hand, a much clearer view of the situation is obtained by such separate study if the interrelationship between burner, furnace, and charge is kept in mind. In the present chapter, combustion devices and heating elements are discussed, with the mental reservation that the study of these devices covers only part of the problem.

It should be noted that auxiliary devices, such as gas producers, reversing valves, pumps, oil heaters, coal pulverizers, piping systems, transformers, etc., are not described in this chapter because they are not parts of industrial furnaces.

No matter what fuel or other source of energy may be used in a furnace, it should be burned (or otherwise applied) in such a manner that the following requirements are met, at least approximately.

1. It should be possible to maintain a given furnace temperature, and that temperature should be controllable even if the demand for heat varies.
2. The temperature distribution in the heating chamber should be arranged to give a properly and uniformly heated product.
3. The nature of the atmosphere in the furnace (oxidizing, neutral, reducing) should be controllable.
4. The furnace atmosphere should not vary to any great extent at different parts of the hearth.
5. The combustion device must not be destroyed by the heat of combustion.

Although these requirements sound simple, they are, in their entirety, quite difficult of fulfillment, as the following reasoning will prove.

If the combustion of fuel is the source of heat energy, the temperature of a particle of the products of combustion at any given spot in the combustion chamber or heating chamber is the resultant of heat addition by combustion and heat abstraction through radiation, convection, and conduction to or from the particle under consideration, all measured from the time when the fuel particle entered the combustion chamber.

In the history of an elementary quantity of fuel and air, two extreme cases may be considered. In one (case A), fuel and air are very thoroughly mixed, and combustion is practically instantaneous. The products of combustion reach their highest temperature almost instantly (the heat is "sharp" or "rash") and impart the highest temperature to the furnace near the place where the fuel enters, causing those parts of the furnace which lie near the discharge flues to be comparatively cool. In the other extreme (case B), fuel and air flow side by side and mix gradually, with the result that the combustion is slow and extends throughout the length of the furnace, reaching occasionally beyond the furnace into the flues or the stack and, in some cases, even beyond the top of the stack. In this case, we speak of a "lazy" flame.

In case A the temperature distribution is uneven, unless modified by recirculation (see Volume I, Chapters I, II, and VI) or by a multiplicity of small burners, but the furnace atmosphere is constant; whereas in case B the temperature is quite uniform, with variable furnace atmosphere. It is evident that in case B there must be uncombined oxygen in the early part of the gas travel. Between these two extremes many intermediate combinations exist, some of which come rather close to the ideal conditions indicated in items 1 and 4 of the requirements given above. It is the purpose of this chapter to consider devices for combustion and for the liberation (release) of heat, with these five points in view.

Before the devices for the different fuels are investigated, the following general statements should be made: Temperature, whether caused by the combustion of fuel or by electricity, is raised (up to a certain limit) by increasing the supply of heat; it is lowered by reducing the supply of heat. For a given temperature, the furnace atmosphere is made more reducing by introducing more fuel and less air. It is made more oxidizing by introducing less fuel and more air.

Two more statements are in order: The best burner cannot deliver more heat than is in the fuel (and air mixture), and there is no such

combination as a perfectly marvelous burner and a relatively unimportant furnace.

Combustion Devices for Gaseous Fuels

General Remarks on Gas Burners. Gaseous fuels are by far the easiest to control and regulate. Opening a valve wider turns on more fuel; the partial closing of the same valve reduces the supply of the fuel. Gas and air can be mixed quickly or slowly, in conformity with the requirements of each individual case.

This apparent ease of control is probably the reason why it took so long, in comparison with the much earlier development of commercial oil burners, to develop good commercial gas-burning devices.

Tests have proved that the equilibrium constants of physical chemistry need not be considered in the combustion of gaseous fuels in industrial furnaces because combustion rates are, from a practical standpoint, infinitely rapid. In other words, if a molecule of gas and a molecule of oxygen meet while above ignition temperature, the reaction is instantaneous. The logical consequence is that speed of combustion is identical with speed of mixing. In an intimate mixture of gas and air, combustion begins as soon as the mixture has been brought up to ignition temperature. Burner design, therefore, is primarily mixer design. Recognition of this fact leads to the understanding that for all burners (except those with complete premixing) the design of the combustion chamber (together with shape and temperature of charge) has a profound effect upon the process of combustion, with regard to space as well as to time.

If an extremely high rate of heat release is an object, the perfect mixture of fuel and air must be rapidly heated to ignition temperature. In a fuel-and-air mixture flowing from a burner into a furnace, the speed of flame propagation and the thickness of the gaseous stream determine the time that is needed for bringing the center of the stream up to ignition temperature. It follows that combustion is most rapid, if gas and air issue from the burner in thin jets or ribbons.

Before the classification of burners is given, a few remarks on lighting up may be appropriate. If either gas or a gas-air mixture is admitted to a cold furnace and if a lighted torch is thereupon applied, a more or less destructive explosion results. In order to prevent explosions, furnace designers provide lighting holes, pilot flames, or spark plugs. These precautions are discussed in Chapter VII.

Classification of Burners

I. A. Gas and air are mixed in the furnace, i.e., during combustion; see the sketch, Fig. 18.

B. Gas and air are mixed outside the furnace, i.e., before combustion begins; see Fig. 19.

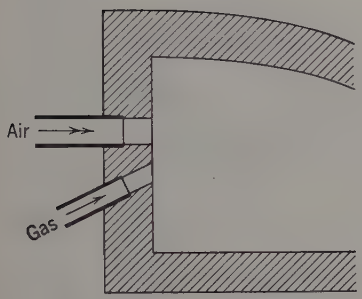


FIG. 18. Simple burner arrangement for mixing gas and air in the furnace.

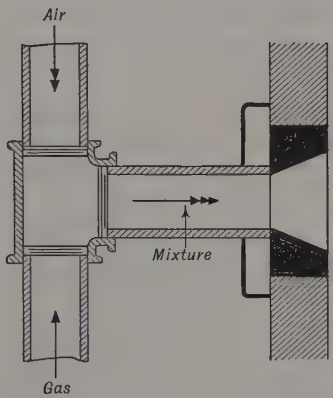


FIG. 19. Simple form of mixer for gas and air.

C. Gas is mixed with some air outside the combustion chamber; the rest of the air is added in the furnace, see Fig. 20. This arrangement requires a slight vacuum in the furnace.

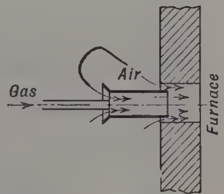


FIG. 20. Diagram of burner with partial outside mixing of gas and air.

II. A. Gas and air have pressure in excess of that of the atmosphere.

1. The pressure is produced mechanically.
2. The pressure is produced by stack effect (buoyancy).
   a. Gas and air valves are separately adjustable.
   b. Gas and air valves are interconnected.

B. Either gas or air is under pressure and, by its velocity of discharge, entrains the other fluid or a mixture of air and gas, reconverting some of the velocity head into furnace pressure.

III. A. Combustion starts from one large burner.

B. Combustion starts from many small burners.

IV. Cracking and mixing burners.

It is inadvisable to describe the combustion devices for gaseous fuels under all these classifications because too much repetition would be caused by such a procedure. Instead, classification I will be used, and attention will be called to the other classifications as the devices are described.

Devices Which Mix Gas and Air in the Furnace. Inside mixing is correct procedure for raw producer gas and preheated air. Although the use of producer gas has declined in the United States, devices for inside mixing of these gases are retained in the present edition because many copies of earlier editions went to countries in which producer gas is still the most important fuel for industrial furnaces. In the firing of raw producer gas the furnace often has no burners but has "ports." This statement refers particularly to reversing furnaces, in which the same furnace elements serve alternately as inlet ports and as exit ports or vents. Oxide, dust, and slag are apt to clog the ports if they are small. In recuperative furnaces the ports may be made small and may be designed properly to constitute burners rather than ports.

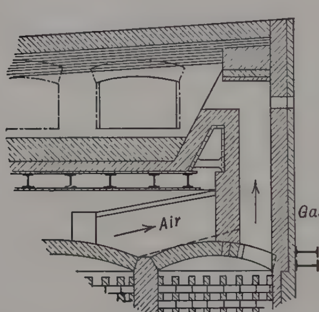


FIG. 21. Ports for air and raw producer gas in regenerative heating furnace.

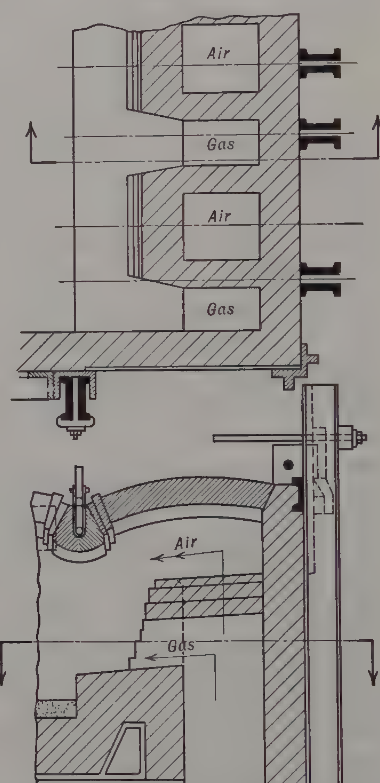


FIG. 22. Ports in regenerative heating furnace. Note that gas is admitted below air.

Ports of regenerative heating furnaces are shown in Figs. 21, 22, and 23. It will be observed that ports are openings in the wall from

which gas and air flow out side by side. The question of flame length resulting from various port designs concerns every furnace designer. If gas and air pass out in parallel streams and with approximately equal velocity, combustion takes place mainly by diffusion of gas and air through each other, aided by the increase of volume due to combustion. The diffusion angle may be taken to be 3 degrees on each side. Combustion will be complete when the edge of one jet has diffused beyond the center line of the adjacent jet.

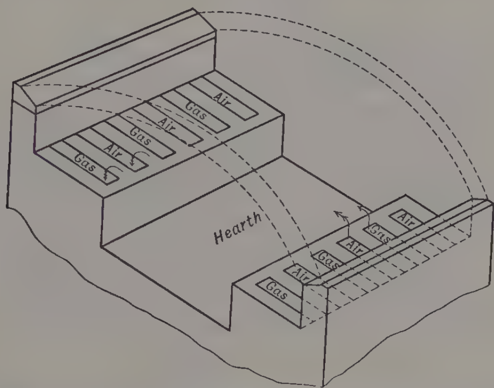


FIG. 23. Perspective view of part of skelp heating furnace. Note arrangement of gas and air ports.

The diffusion angle of 3 to 4 degrees does not hold if one of the fluids (gas or air) has a much higher velocity than the other, or if the gases impinge upon obstructions. In such cases, diffusion gives way to induction or entrainment (see Volume I) or turbulence, and the act of mixing is quickened.

The permissible velocity of air and gas in passing through the ports of regenerative furnaces is discussed in Volume I, Chapter VI.

If furnaces (having ports as shown in Fig. 23) are very long, that is to say if many ports lie side by side, it is difficult to obtain the correct distribution of flow through the multitude of ports because of inertia and friction in the low-lying horizontal supply ducts (manifolds).[1] The ports are usually built a little too large and are experimentally covered by tiles that are made of high-alumina brick or of silicon carbide until the desired temperature distribution (along the length of the furnace) has been obtained. To that end, openings

[1] The design of manifolds for uniform distribution was investigated by J. D. Keller in *Industrial Heating*, March 1952.

filled with removable bricks (blinds) are provided in the furnace wall immediately above the ports in order to afford access to the ports.

If the stock being heated is of such a nature that it would suffer damage by oxidation, the gas ports are located under the air ports for the purpose of bathing the charge in gas rather than in air.

If the stock is to be heated mainly by radiation, the ports face the roof as in Fig. 23, directing the flame along the roof.

If highly preheated air flows through ports always in the same direction, the ports can be made smaller and more numerous than

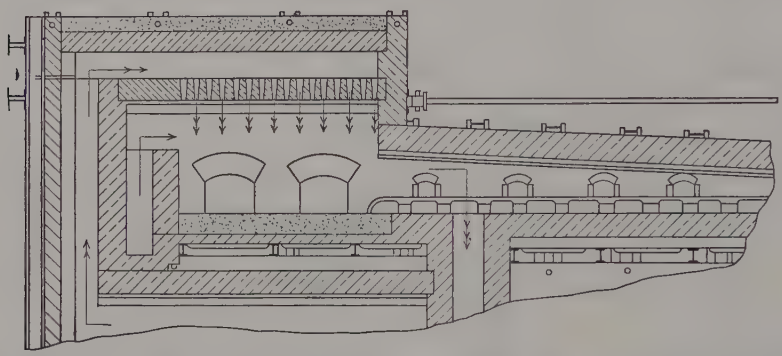


FIG. 24. Continuous furnace with overfired soaking hearth. Note many small ports for preheated air. Penetrating air jets mix with gas blanket below them.

they can be in reversing furnaces. Examples of furnaces with many small ports for preheated air are shown in Figs. 24 and 25. In Fig. 24 the ports are distributed over a large portion of the roof. This arrangement results in the maintaining of a practically uniform temperature over the whole soaking hearth and produces a so-called reducing or neutral atmosphere at all places on the soaking hearth. Fig. 25 represents ports at the inlet end of a continuous furnace. The purpose of this design is the quick mixing of air and gas, without stratification. The velocity of the air through the ports should be such that it is practically all spent by the time the vertical air jet reaches the bottom of the horizontal gas jet. The finer the air holes, the higher the air velocity must be to penetrate a given distance downward. The theory of jets is explained in Volume I.

Mixing of air and gas in the furnace is not limited to producer gas or blast-furnace gas. When a more convenient fuel becomes available for replacing producer gas, the existing furnace is frequently retained; both air and gas regenerators preheat air which is delivered through all ports. The new, rich gas enters the furnace through

many small pipes, each of which is located over an air port. Many furnaces of such design are now in operation for heating skelp.

Fig. 26 illustrates inside mixing with admission of air in two stages. The design was abandoned for furnaces in which a high flame temperature is required. In such furnaces gas and primary air must be well mixed.

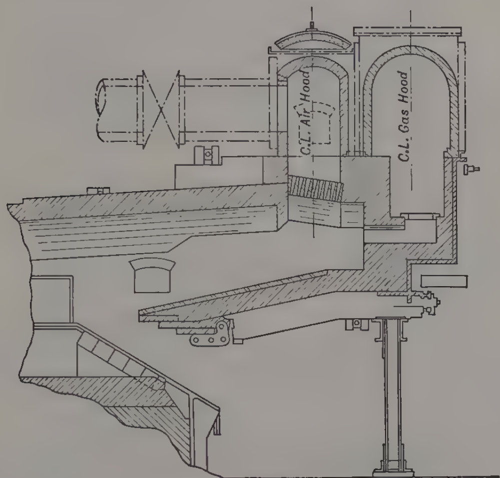


FIG. 25. Discharge end of continuous furnace. Note that gas enters below air, which enters in many small jets, at right angles to gas flow.

Proof for the statement that burner and furnace together form an integral combustion device is furnished by Fig. 27. In this arrangement a long, luminous flame is laid over the hearth. Coke-oven gas and part of the required air are admitted at the foot of a shaft in

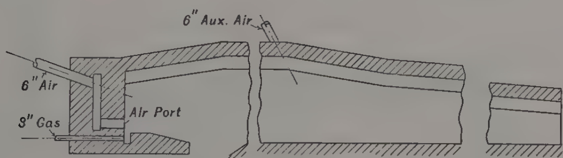


FIG. 26. Inside mixing of gas and air in two stages.

which partial combustion and cracking take place. Final combustion and flame direction are caused by secondary air which is admitted above the hearth level. The principle is similar to (but better than) the arrangement shown in Fig. 26; initial and partial combustion take place not over the hearth but in a separate combustion chamber.

Outside mixing, that is to say, premixing of gas and of highly preheated air, presents difficulties (which have, however, been overcome). The difficulties are avoided by inside mixing. Fig. 28 illustrates one

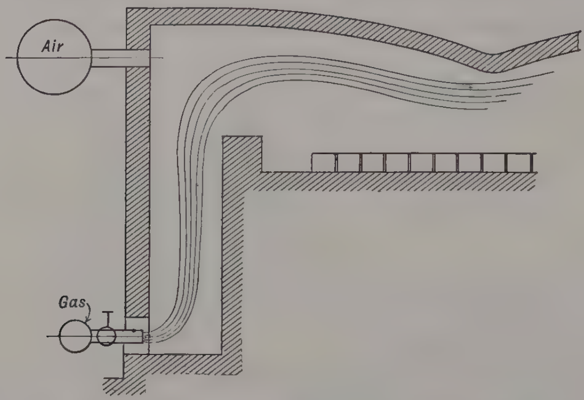


FIG. 27. Combustion device for producing a long, luminous flame. A forerunner of the cracking and mixing burner.

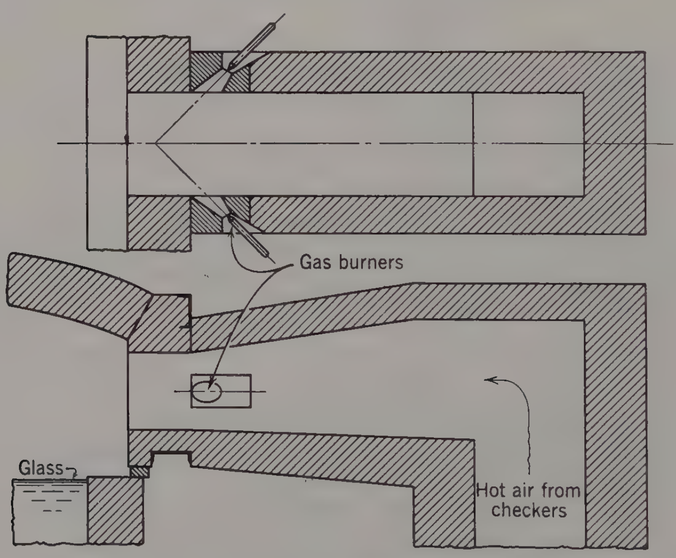


FIG. 28. Standard inside-mixing burners for glass tanks.

method. Highly preheated air rising from the regenerator flows through a port. Near the entrance to the furnace, gas enters through pipes into taper burner blocks, one on each side. Diameter and taper of the burner blocks are so dimensioned that the cracking gas cannot

touch the walls of the burner block. If it touched, the burner would be "fouled" by deposits of carbon. The design of Fig. 28 is standard in furnaces for melting glass.

If the gas duct and the air duct of Fig. 18 are set to almost touch each other, a wide range of speed of combustion can be attained by varying the relative inclination of the two jets. Impingement at

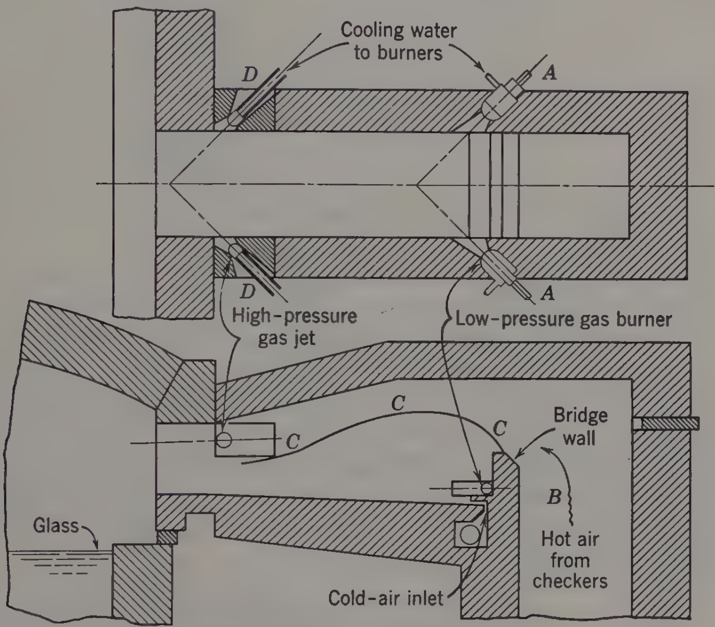


FIG. 29. Cracking and mixing burners for glass tanks.

about 45 degrees results in quick combustion. Almost parallel streams of gas and of air result in slow combustion and in a long flame. If the impingement angle is made adjustable, the furnace operator can change the characteristic of the flame while the furnace is in operation. If the gas contains hydrocarbons, his adjustment also varies the luminosity of the flame.

Flame luminosity, which is caused by glowing carbon particles that float in the flame, is very desirable in furnaces of certain types. The combustion device of Fig. 28 has been modified to work with adjustable luminosity. The modification is illustrated by Fig. 29 and bears the name "cracking and mixing" burner. A more descriptive but longer name would be "cracking port and mixing jets." In this combustion device a rich gas enters slowly through lateral pipes *A*. Pre-

heated air rises in uptake *B*. Partial combustion takes place along surface *C-C-C*. Radiation from this surface cracks the gas that flows underneath. If all of the required gas enters through pipes *A*, the flame is dull and smoky and smoke is visible even at the top of the stack. At *D* high-pressure jets of fuel gas are provided. If all

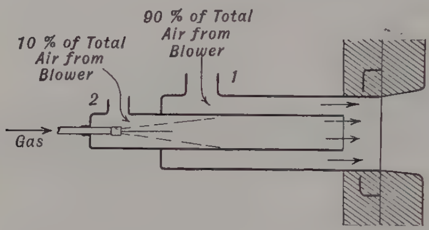


FIG. 30. Burner with adjustable flame luminosity.

of the required fuel gas enters through jets *D*, a violet-blue haze of extremely hot gases is observed. By varying the ratio of high-pressure gas *D* to low-pressure gas *A*, the operator may obtain any desired degree of luminosity.

Cracking of the fuel gas produces small carbon particles, some of which attach themselves to the walls of the port. Unless this carbon is burned off in the early part of the reversal, it leeches the silica out of the firebrick by the reactions: $SiO_2 + 2C = Si + 2CO$ and $SiO_2 + 2CO = Si + 2CO_2$. The free silicon burns to silica which is carried partly into the furnace.

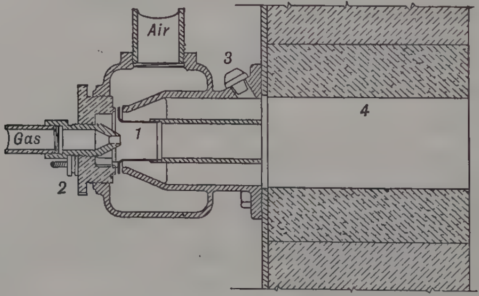


FIG. 31. Commercial burner with adjustable flame luminosity.

Although the combustion arrangements illustrated by Figs. 27 and 29 are part of the furnace, commercial burners involving the same principle are on the market. They are called luminous-flame burners or smoke burners. In such burners the gas is mixed with a fraction of the combustion air and is cracked while burning in a tube. The

main stream of the combustion air passes through an annular channel between the cracking tube and an outer surrounding tube. Mixing with secondary (main-stream) air is started in the burner block. The length of travel, at the end of which mixing is completed in the furnace (or beyond the furnace), depends upon diameter and design of burner. A burner of this type is illustrated in Fig. 30. It is difficult to predict that ratio of primary air to secondary air which will produce the best luminosity and transfer of heat. It is also neces-

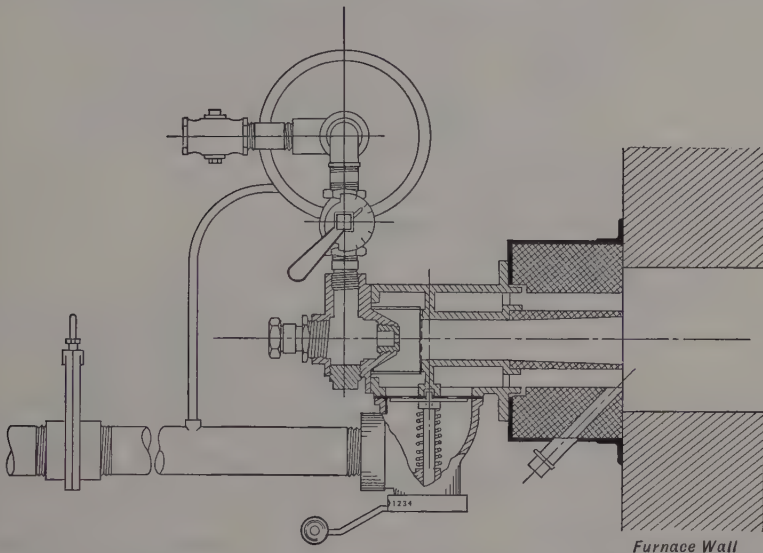


FIG. 32. Burner with graduated scale for adjusting flame luminosity.

sary to keep the ratio between primary and secondary air constant when the flow of fuel gas and of air changes. Both features have been built into the burner which is illustrated by Fig. 31. By turning nut (2), the short tube (1) is adjusted longitudinally. The total area for air flow on both sides of the flange of tube (1) is not changed by the adjustment. Item (3) is a lighting hole, and (4) is the burner tile, which has been shown with a cylindrical hole. A flaring hole would be better.

The same principles are embodied in the burner which is illustrated in Fig. 32. The added feature consists in a scale (near the adjusting handle at the bottom) which indicates the ratio of primary air to secondary air. The handle near the top adjusts the gas-to-air ratio. A lighting hole is provided and also a Pyrex-glass window for observation of flame.

Luminosity can also be produced by cracking the gas in the burner tile. To that end, a collar is attached to the discharge end of the central gas tube, as shown in Fig. 33. The collar has two effects: It is the root of a large conical surface in which some gas burns; it also causes the gas to flow so slowly that time is available for cracking.

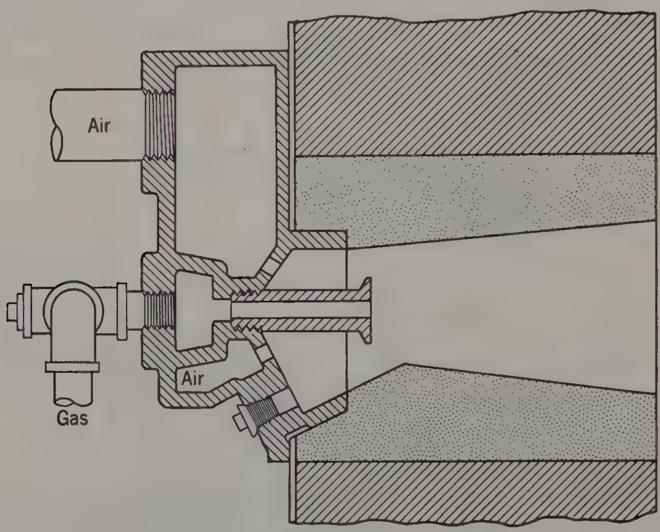


FIG. 33. Long-flame burner with cracking of gas in burner tile. Courtesy of Bloom Engineering Co.

According to earlier statements in this section, burners with adjustable luminosity should be preferred; but the sales records show that burners with a fixed length of luminous flame are generally preferred. They are less expensive, and the makers of burners have learned to install burners having the correct flame length for a given furnace and a given fuel.

In all smoke burners, it is important to keep fuel which cracks in the absence of air (or in the presence of an insufficient amount of air) away from hot walls. Along a wall, the velocity of flow of gas is very low. In consequence, more time is available for cracking. Since the gas flows slowly along the hot wall, its temperature exceeds that of the rest of the gas. For both reasons, it cracks much more rapidly than the rest of the gas and builds up coke on the wall, finally choking the port. The influence of time and temperature upon cracking may be seen by studying Fig. 34.

Combustion Devices with Partial Premixing. The borderline between all-inside mixing and partial premixing is very indistinct. The

long-flame burners, for instance, work with a slight premixing. Partial premixing, in contradistinction to the long-flame burners, results in a quicker combustion.

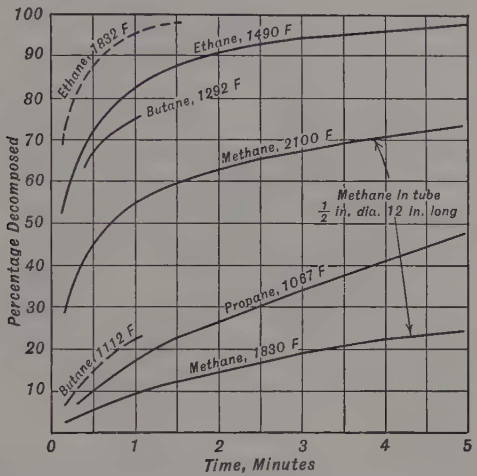


FIG. 34. Effect of time and temperature on the cracking of hydrocarbon gases.

The most widely used burners with partial premixing are the nozzle-mix burners. Gas and air are admitted through alternating concentric rings or through alternating radial slots. Complete combustion is secured even without the aid of combustion blocks. An

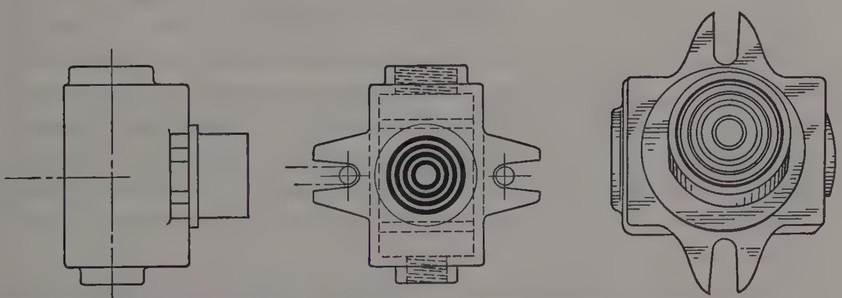


FIG. 35. Nozzle-mixing burner spouts alternate rings of gas and air.

example is shown in Fig. 35. The combustion secured by this type of burner is somewhat slower than it is with complete premixing. A large combustion chamber is recommended.

As compared with the premixing burners, which are discussed later, the nozzle-mixing burners have the advantage of wide turndown

range. The flame also has some luminosity. If mixing occurs immediately ahead of the entrance to the nozzle, the burner is called a nozzle-premix burner.

Among the nozzle-premix burners some come very close to total premixing, as for instance the burner of Fig. 36, which is widely used in German steel works. Air enters tangentially into a sphere and is expected to whirl in it, drawing the gas into the whirl and mixing with it. At low turndowns the whirl and the mixing are likely to be absent, or at least very poor. The central gas pipe or sleeve is adjust-

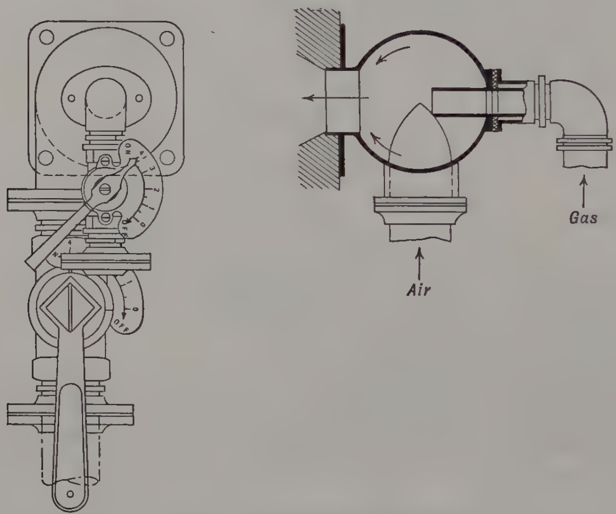


FIG. 36. Globe mixer and burner.

able. When its mouth lies in the center of the sphere, the mixture is reasonably complete in the burner block (burner tile). This position is used for highly preheated air (up to 750 F) and coke-oven gas. With lower air temperature, the sleeve is pulled back because combustion is slower. The air pressure is about 8 in. of water. This burner is made in various sizes to burn from 6 up to 120 cu ft of coke-oven gas per min.

In the burner of Fig. 37 gas and air are whirled in opposite directions into an annular mixing chamber. With wide-open control valves, mixing is almost complete. At turndown it is poor.

Prenozzle mixing is obtained in the burner of Fig. 38. The intensity or degree of premixing can be adjusted by several means. The length 1–2 of the mixing cone may be changed in relation to the diameter of the pipe. If 1–2 is very long, good premixing is obtained. The mixing (which takes place in a 20-degree cone) is complete if the

20-degree cone lies entirely within the tube. Quicker mixing is obtained if the gas has a high velocity, considerably in excess of that of

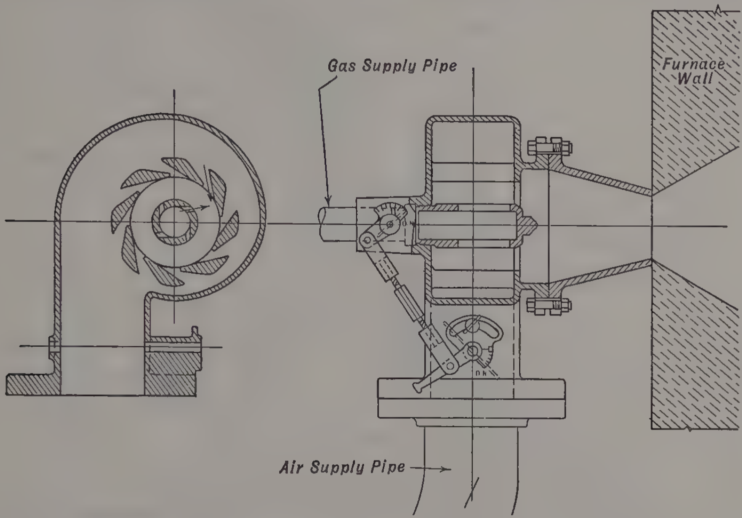


FIG. 37. Nozzle-premix burner with opposite whirls.

the air. If enough gas pressure is available, the size of the gas pipe is left unchanged, but the pipe is capped at point 1 by a tip or a nozzle or else it is swedged down. The size, number, and arrangement of holes in the cap have a decided influence on the degree of premixing. If the burner is designed so that gas pipe and cap can be pulled out of the air pipe, caps can be changed quite easily, and different types of flames can be obtained. If adjustment of quickness of mixing is to be obtained while the burner is in operation, the modification shown in Fig. 39 may be used. Gas is admitted through the central pipe as in Fig. 38 or through fine holes in the circumference of the air pipe, or through both.

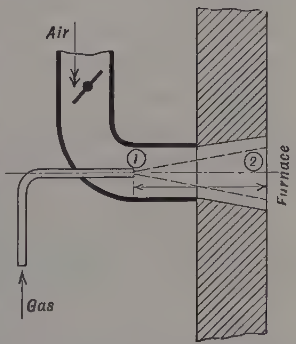


FIG. 38. Simple nozzle-mix burner.

Burners such as shown in Fig. 38 are often used for firing into wide furnace fronts. Observation of the flame condition of each burner is then very desirable. Such observation can be had through a glass-covered hole in the bend in the gas pipe or the air duct. The arrangement of Fig. 40 permits flame observation without a peep hole, but

cannot be recommended for industrial furnaces. In order to aspirate secondary air against furnace pressure the velocities of gas and of blower air must be very high. And if the opening is provided for observation only, variation in furnace pressure either sucks in some excess air or else blows flame out of the opening into the room. This statement holds true for all burners that do not fit close but leave an opening between burner and furnace. Such burners should be avoided for industrial furnaces. They are useful for furnaces in which a slight vacuum exists; examples are certain boiler furnaces and ceramic furnaces, in which stack draft produces a fairly constant small vacuum. A practical application of a gas-burning device, in which both gas and air are delivered under some pressure and the mixture (aided by furnace draft) induces additional air, is shown in Fig. 41. In this case it is intended to produce an oxidizing atmosphere for burning clay products.

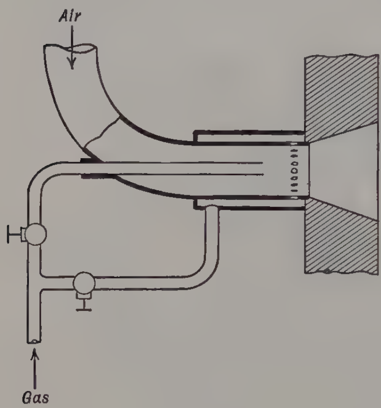


FIG. 39. Burner with adjustable speed of mixing.

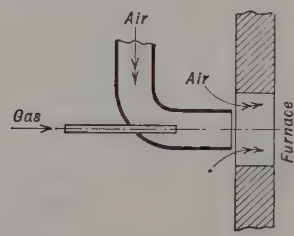


FIG. 40. Simple nozzle-mix burner for furnaces with less than atmospheric pressure.

Raw producer gas is supplied to furnaces at a very low pressure, because the tar would foul any pressure-increasing blower and because any pressure exceeding 1½ to 2 in. of water (depending upon producer design) causes the gas to bubble through the water seals into the producer house. At the furnace, the gas pressure is less than this amount on account of the frictional resistance of the gas ducts. Whenever air under pressure is available, partial premixing and positive flame direction can be obtained by letting the air stream assist in the flow of producer gas. Such an arrangement is illustrated in Fig. 42. Insulation of the air pipe indicates that the air was preheated.

If neither the gas nor the air has enough pressure for induction, mixing, and flame direction, a jet of high-pressure blower air can

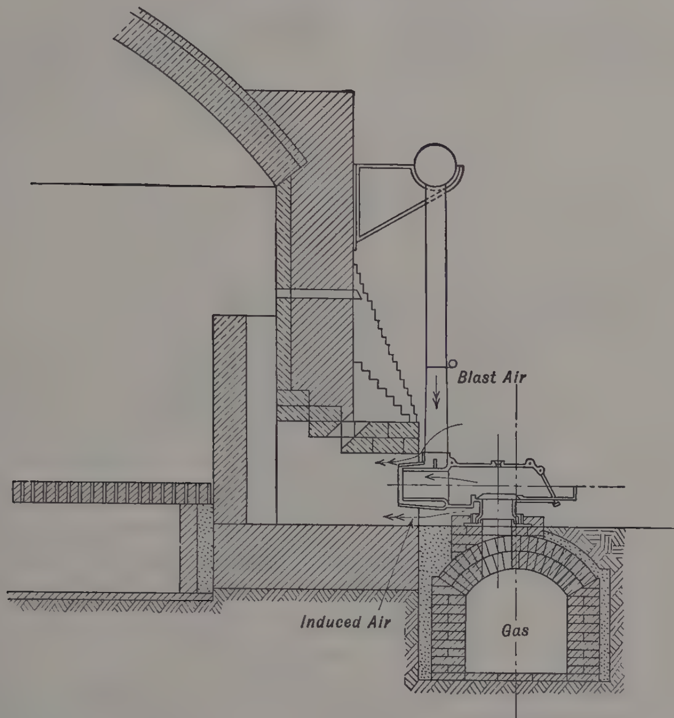


FIG. 41. Nozzle-mix burner for producer gas. A large fraction of the combustion air is induced by stack draft.

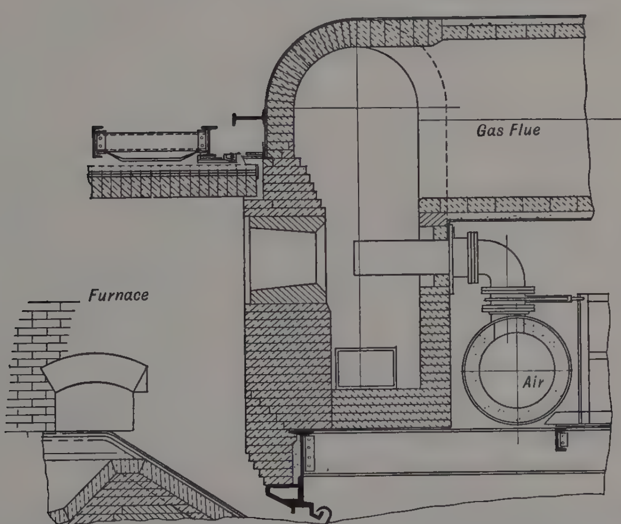


FIG. 42. Inspiration of producer gas by preheated air.

impart momentum to the combustion air and then to the gas. This arrangement has been applied in practice to furnaces with tile recuperators; it is shown in Fig. 43. It will be noticed that blower air

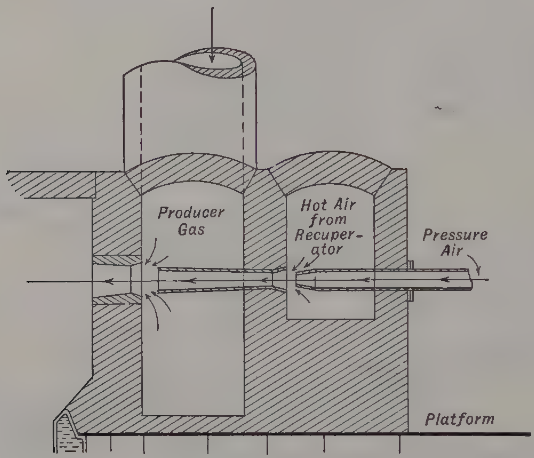


FIG. 43. Inspiration of producer gas and of preheated air by blower air.

induces the hot air which arrives with atmospheric pressure from the recuperator and that the resulting air jet produces mixing, gives direction to the flame, and assists in the flow of producer gas.

In the combustion devices of Figs. 42 and 43, the length of the flame depends upon the diameter of the burner, on the composition of the fuel gas, and on the shape of the port (burner block). If the arrangement of these illustrations produces too short a flame, which is localized and concentrated, combustion can be slowed down by various means. One means consists in making the burner block oval instead of circular. The effect of the oval burner opening is the following (see Fig. 44): The gas stream near the air nozzle (points 1 in the illustration) mixes quickly with air, whereas the gas flowing in the extremes of the ellipse (such as points 2) mixes more slowly and burns later. The effect of the oval port is the same for all fuel gases.

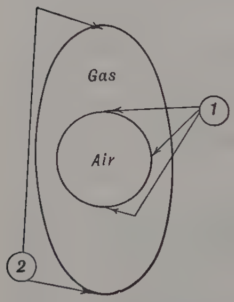


FIG. 44. Burner mouth for long flame.

Burners for Premixed Air and Gas. Complete premixing results in the greatest heat release per unit of combustion volume or, which

means the same thing, in the smallest combustion volume for a given rate of heat release.

As previously stated, complete premixing of fuel gas and of air may be accomplished by one of several means. Gas and air may be brought to the burner in separate ducts and mixed at some distance ahead of the burner; or they may be mixed in a pump (fan blower or displacement pump), or else one of the component parts of the combustible mixture may be used to aspirate the other component part of the mixture. The relative merits of these devices are discussed in the chapter entitled Control of Furnace Atmosphere.

Several burners described under Combustion Devices with Partial Premixing can be designed so that total premixing ahead of the burner tile results. Fig. 38, already referred to, is an example of the effect of a comparatively small change in dimensions. If the horizontal section ahead of the furnace is made so long that the mixing cone fills the duct ahead of the burner tile, premixing is almost perfect, especially if the furnace wall is thick. If turndown causes flashback, additional, smaller burners are installed for periods of reduced heat input.

All combustion devices that involve complete premixing of fuel and air, before the mixture enters the burner tile, have certain features in common, which will now be discussed. In order to prevent backfiring (flashback, backlighting), the combustible mixture must enter the furnace chamber with a velocity which is in excess of the velocity of flame propagation. The greater the velocity of the combustible mixture, the greater is the distance from the point at which the mixture enters the combustion chamber to the point at which combustion begins, unless means are provided to slow down the stream or, at least, part of the stream. As a matter of fact, combustion always begins at the place where the velocity of flow equals the velocity of flame propagation, provided the mixture is at or above ignition temperature. If the velocity at entrance exactly equals the velocity of flame propagation, a limiting case is reached and the flame may extend back into the mixing tube. Because of flashback, the furnace cannot be operated at a lower rate of fuel supply than corresponds to the limiting case. The ratio of flow at rated capacity to flow at flashback is called the turndown ratio or, for short, the turndown. Values for velocities of flame propagation are given on page 72. In the attempt to obtain a large turndown two effects must be kept in mind. (1) The higher the velocity of the entering gas and air mixture at rated load, the greater is the turndown or, in other words, the lower is the rating at which the furnace can be operated without flashback. (2) The

section at which the highest velocity occurs must be kept fairly cool because the velocity of flame propagation increases with the temperature.

The original designs of burners that operate with high-mixture velocities are illustrated by Figs. 45 and 46. In the device in Fig. 45 the flow is slowed down by (and a definite location for combustion is provided in) broken refractory material. In Fig. 46 the mixture is slowed down at the exit from an upwardly directed burner. A definite location for combustion is provided by fanning out the stream along the incandescent roof. Combustion on the surfaces of broken refractory material or a roof is now rarely encountered. Instead, flaring burner tiles equipped with pilot flames are used. Such a burner is illustrated by Fig. 58. If the velocity is too great, the flame is blown away from the burner tile and hangs like a "will-o'-the-wisp" somewhere in the furnace. A steady pilot flame prevents the blowing off. Fig. 47 diagrammatically illustrates the location of the root of the flame at different rates of firing. With capacity firing, the flame root should be at 1. As the mixture supply is throttled, the flame root travels through sections 2 and 3 to 4. Further reduction of velocity results in flashing back. If the burner is large, the furnace wall must be very

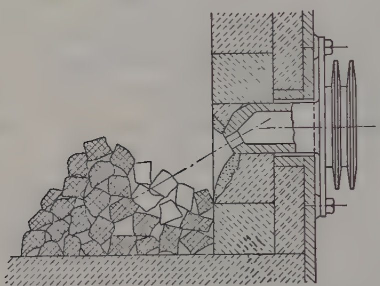


FIG. 45. Gas burner throwing jet of burning mixture into loose refractory material.

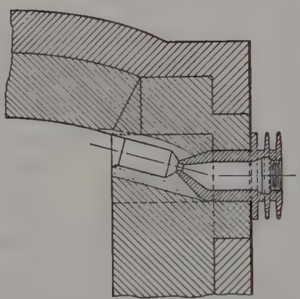


FIG. 46. Burner nozzle spreading sheet of burning gases under arch.

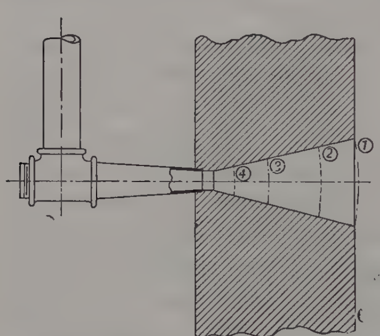


FIG. 47. Location of plane of ignition at varying rates of flow.

thick in order to accommodate an ignition cone of the proper angle and length.

The difficulty is overcome by the installation of cylindrical or tunnel burners of proper design. The burner that is illustrated by Fig. 48

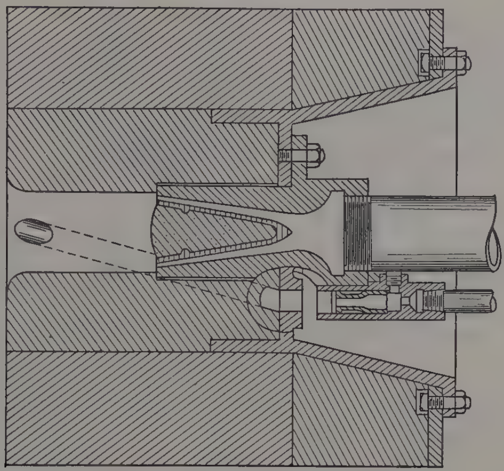


FIG. 48. Antiflashback burner port. Courtesy of Mid-Continent Metal Products Co.

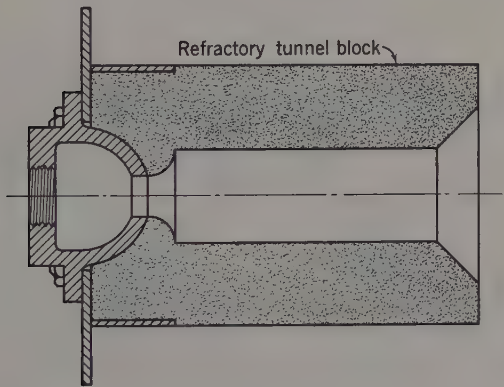


FIG. 49. Tunnel burner with protection against overheating. Pilot lies in front of plane of drawing.

is scientifically correct. The explosive mixture that flows at high velocity through the annulus is directed against the walls of the cylindrical burner tile, which become incandescent immediately after lighting up. Friction and turbulence reduce the velocity in the tunnel.

As previously mentioned, burners for explosive mixtures must be

protected against overheating. In the tunnel burner Fig. 49 the metallic parts are protected by refractory material. The burner of Fig. 48, already referred to, is likewise protected by refractory material. Means (not shown) is provided for holding the refractory cone

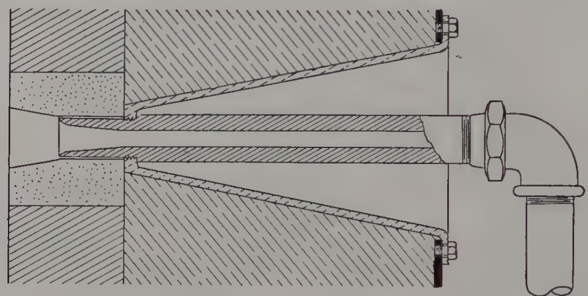


FIG. 50. Burner port with thick-walled tube and open well for dissipating heat.

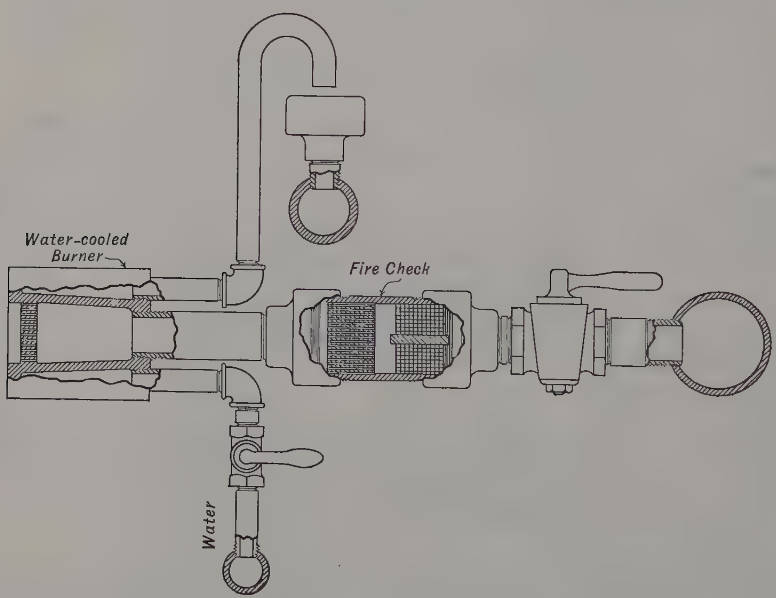


FIG. 51. Water-cooled needle burner with fire check.

in place. The older burners, Figs. 45 and 46, depended upon dissipation of heat for protection against overheating. In Figs. 45 and 46, cooling fins outside the furnace wall are easily identified. Some more recent burners also depend upon conduction and dissipation of heat for protection. Fig. 50 exhibits this fact very clearly. In this

burner, the furnace end of the burner is not protected by refractory material.

As shown below, the velocity of flame propagation grows with the diameter of the tube through which the explosive mixture flows. For that reason, it is logical to split up the main stream into many small

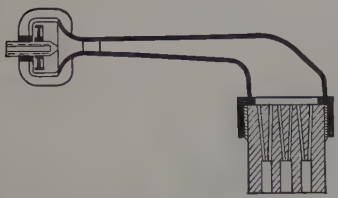


FIG. 52. Burner with surface combustion in perforated brick.

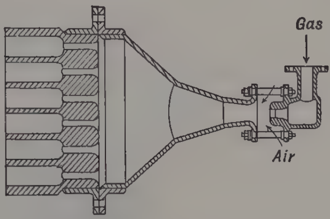


FIG. 53. Burner with surface combustion in perforated brick.

streams at entrance into the furnace. Fig. 51 is an extreme example of stream splitting. The burner (at the left end of the illustration) is a "needle" burner. The sharp, bluish flames of extremely small diameter look like needles. This burner is well protected against flashback. Not only is the burner water cooled, but a fire check is arranged in the supply line.

Even without water cooling, safety against flashback is increased by subdivision into many small streams. In Figs. 52 and 53 small

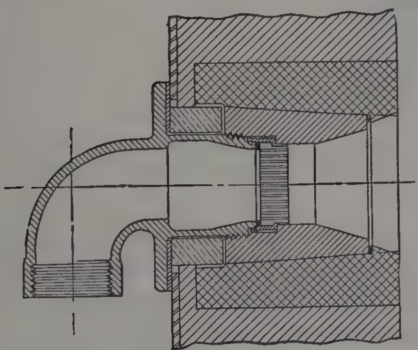


FIG. 54. Burner with refractory screen.

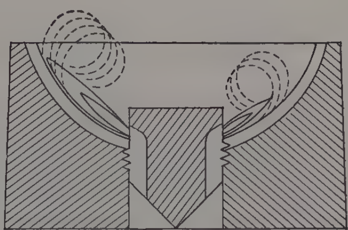


FIG. 55. Burner with radiant cup.

holes are made in thick refractory blocks. These burners were developed in Germany, where they were called *Steinstrahl Brenner* (refractory jet burners). Although combustion begins in the enlarged sections of the perforations, temperature does not crawl back because the conductivity of the block is very low and because the incoming

mixture moves the heat towards the discharge end. The design of Fig. 54 is less safe because the refractory screen has very little thickness. The burners of Figs. 52 and 53 produce short flames, which look blue in the open and which are invisible in the furnace.

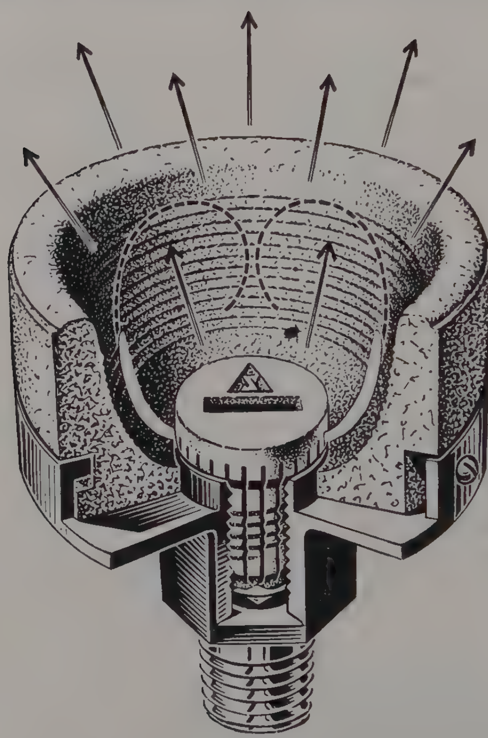


Fig. 56. Cutaway view of the burner shown in Fig. 55. Note the narrow slots for discharge of explosive mixture. Courtesy of Selas Corp. of America.

The successful use of refractory multijet burners (Figs. 52 and 53) led to the thought that porous (burned-out) bricks would be even better than perforated blocks and would also be less expensive. The porous bricks would be better, because the walls and the roof could possibly glow with a uniform radiant heat. Experiments were made with porous bricks from different makers, but the results were all disappointing and caused the scheme to be abandoned. The pores in bricks are extremely irregular. Some pores are interconnected and pass through from one side of the bricks to the other side, but other pores are sealed or closed; therefore, some sections of the wall glow brightly while others are black. Further, the pressure that is needed

to force the explosive mixture through the bricks cannot be predicted. These experiments are here related for the purpose of keeping others from having the same bright idea in the future.

The principle of working with many subdivided jets is also embodied in the burner of Figs. 55 and 56, which has found a wide range of

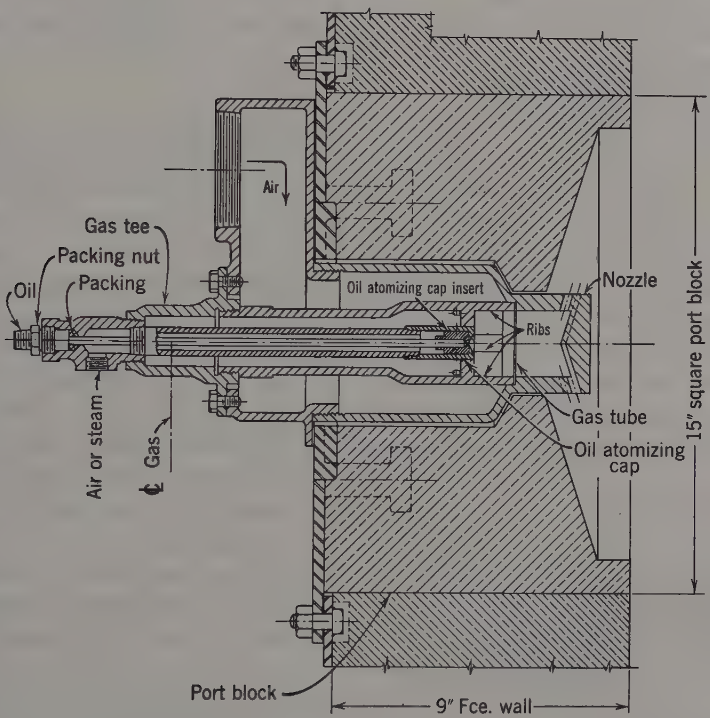


FIG. 57. Burner with rapid combustion of gas. Courtesy of Bloom Engineering Co.

applications. The openings into the burner cup look fairly large in Fig. 55. But Fig. 56 teaches that these openings are narrow slits. Combustion is almost instantaneous at discharge from the slots, with the result that the temperature of the products of combustion approaches the adiabatic (ideal) flame temperature. When this cup burner fires at full capacity into a furnace that carries a high temperature, the surface of the cup reaches a very high temperature. In consequence, the cup and the burner insert are made of a special refractory that can withstand these temperatures without softening, spalling, or crumbling.

Burners with very small or narrow openings for the explosive mix-

ture have two properties in common, namely, rapid combustion and the need for clean fuel. Flame propagation takes place in all directions, including the direction from the flame envelope to the center of the gas stream. The shorter that distance, the shorter is the time in which combustion spreads through the whole jet, provided, of course, that the envelope is above ignition temperature. Both fuel gas and air must be clean enough to prevent clogging of the small or narrow openings. To that end, elaborate gas cleaners have been installed in many cases.

Rapid combustion and close approach to adiabatic flame temperature are likewise obtained by a burner of a very different type. This burner, which is illustrated in Fig. 57, is a combination of primary nozzle mixing and secondary premixing. It does not fit into any classification. Fuel (gas or light oil) and air are mixed in a nozzle and flow into a precombustion chamber, from which the mixture enters the furnace through many small holes that are arranged in two rows around the circumference. The furnace side of the precombustion chamber becomes incandescent, with the result that combustion begins in that chamber. The number and the size of the holes are critical; both are determined experimentally. The burner of Fig. 57 has a considerable turndown ratio. In any event, flashback can go no further than the nozzle. It has been claimed that this burner has a very high rate of heat release, up to 200 Btu per (cu ft, sec).

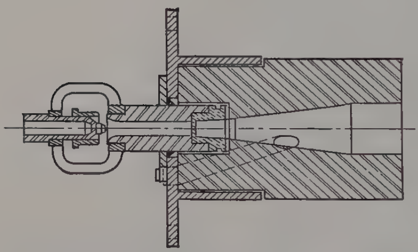


FIG. 58. Combination inspirator and tunnel burner.

The previously mentioned principle of making the explosive mixture enter a burner at high velocity and then slowing the mixture down in a tunnel is also built into the burner of Fig. 58, with this difference: In Fig. 58, a swift jet of fuel gas inspirates the required air. Burners of this type are called inspirator burners, velocity burners, and sometimes blast burners. They are discussed in detail on pages 71–72.

As a rule, the term "blast burner" is more properly applied to burners of the type that is illustrated by Fig. 59. The flame can be observed at all times; it cannot be blown off, because part of the gas-air mixture flows outward through small holes into a cavity, where it burns quietly and serves as a continuous pilot flame. From earlier statements it follows that open (not sealed) burners cannot

be used for direct firing into metal-heating furnaces. They are useful for ceramic furnaces, for steam generators, for firing into radiant tubes, and for those furnaces in which the charge lies in a muffle.

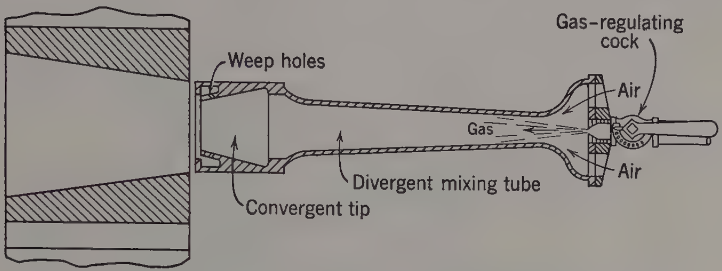


FIG. 59. Inspirator burner with weep holes for ignition at burner.

Burners for Producer Gas. Burners for clean producer gas differ but little from burners for rich gases except in the ratio of cross-sectional areas for air and gas. By clean producer gas is meant a gas that was produced either from coke or from anthracite, or else a scrubbed gas that was made from bituminous coal.

Clean producer gas flows at high speed through pipes, because it can safely pass through centrifugal blowers or through displacement blowers, whereas raw producer gas must flow slowly because the pressure drop cannot exceed the few inches of water pressure that are dictated by the water seal or seals at the producer, and because blowers would be put out of action by tar and dust. True burners (not burner ports) for raw gas must use the pressure of the combustion air for mixing and for helping the gas along. They should also be self-cleaning.

In the design of burners for raw producer gas, this principle is illustrated by Figs. 42 and 43. Embodiment of the same principle in burners is shown in Figs. 60, 61, and 62. Fig. 60 is a longitudinal section through a burner which has been on the market for many years and which has a good sale even now. The general admission of gas is controlled by a valve, which is either wide open or dead shut. Because cold tar freezes, two handwheels are used for controlling the valve. The upper one is used for opening and closing the valve, while the lower one is used only for cracking the valve off its seat.

With the gas valve wide open, the flow of gas is regulated by either the inducing or the baffling effect of a nozzle for blower air, which is shown in Fig. 60 in its proper relation to the rest of the burner, and

which is shown separately to a large scale in Fig. 61. The inducing effect of the nozzle, which introduces all the air used for combustion, is varied by the twisting of a slide or cloverleaf valve in the back

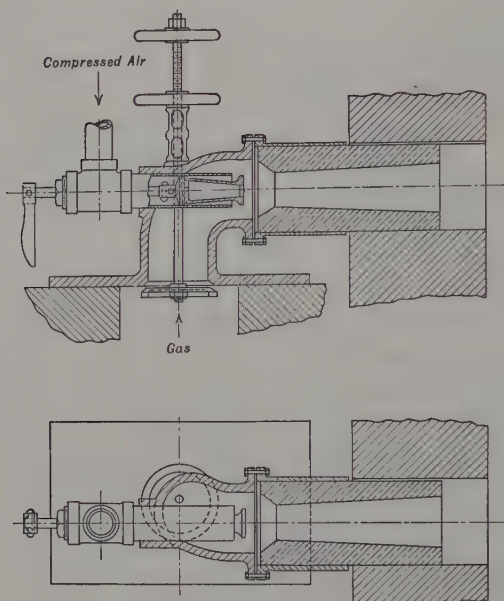


FIG. 60. Burner for raw producer gas. Note the two hand wheels for freeing gas valve when stuck with tar.

part of the nozzle. This valve, as its position is changed, directs varying proportions of the air either through the center or around the outside of the nozzle, allowing any combination between the rates of flow through the two passages. The air which passes through the center of the nozzle produces a strong inducing or entraining effect,

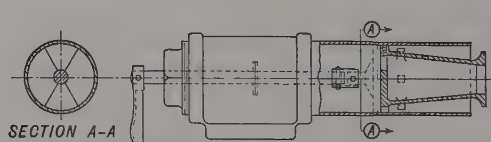


FIG. 61. Nozzle for raw producer gas burner, with valve for regulating induction of gas.

whereas the air passing around the outside is deflected radially at the tip and has a tendency to hold the gas back. Since the purpose of the air nozzle is to furnish air for combustion and to induce the proper

amount of gas, a wide range of regulation is necessary both for quantity of gas and air and for gas-to-air ratio. This dual regulation is obtained by the above-mentioned cloverleaf valve and a throttle in the air line. The gas-and-air mixture passes through an ignition tube of refractory tile which is exposed to backradiation from the furnace. All tarry matter is thoroughly gasified and made ready for combustion in the ignition tube.

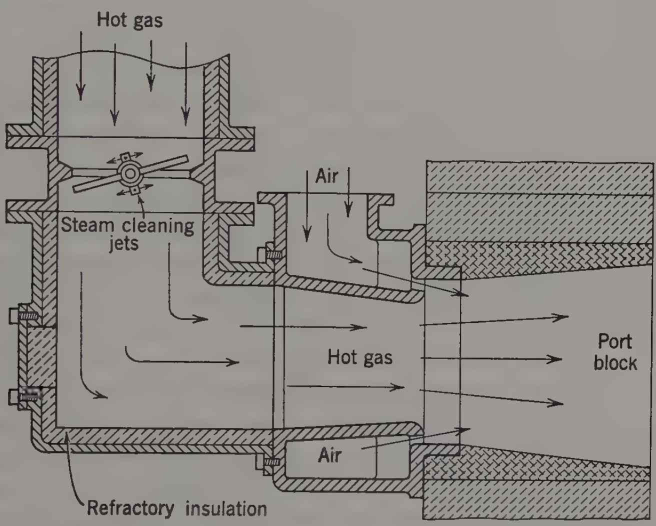


Fig. 62. Burner for raw producer gas. Courtesy of Bloom Engineering Co.

The size of the valve for a given gas flow is varied with the available room. If much space is available, large valves are used, and the air pressure is kept down to 3 oz per sq in. In most cases the pressure can be kept below a pound, but in a few cases as much as 5 psi have to be used. The burner can take care of air which has been preheated up to 700 F.

In the burner of Fig. 62, flow of gas is controlled in a more conventional manner, namely, by a butterfly valve. Semitangential jets of air help the gas on its way and produce the desired mixing effect. The control valve is equipped with steam jets for softening the tar and for removing dust.

Gas Burners for Preheated Air. Preheated air is supplied to gas burners for one of two reasons: either for increasing flame temperature or else for bettering fuel economy. In industrial (metal-heating) furnaces, fuel economy is the principal reason for the preheating of the combustion air.

If the preheated air, preferably having a constant temperature, has pressure energy when arriving at the burner, the principal change in the burner consists in the provision of increased cross sections of the air passages. If the preheated air reaches the burner with a very small excess pressure, such as is produced by the buoyancy of regenerators or tile recuperators, the velocity of the air is so low that it cannot produce good mixing unless the air is propelled by mechanical means. The pressure energy of the fuel gas must then be depended upon. Even if that be done, mixing is usually imperfect. However, the high temperature of the air quickens combustion.

Radiant Gas Burners. A number of different gas burners have been called (and are sold as) "radiant gas burners." Among them are the burners of Figs. 52, 53, 55, and 56. The burner of Fig. 57 is to some extent in that class; partly because the hottest and most highly incandescent part is not the burner but the roof or wall adjoining the burner. The name "radiant gas burner" commonly used in the trade creates the impression that the greatest part of the heat that is released by combustion in the burner is transmitted by solid radiation to the furnace interior and to the charge.

Mr. J. D. Keller experimentally determined the heat that is given off by solid radiation from a burner as a fraction of the heat that is released in (or immediately adjacent to) the burner by combustion.[2] The tests showed that the radiated fraction of the combustion heat reaches a maximum at a low rate of heat release and then drops steadily as the rate of heating is increased. For the burner shown in Figs. 55 and 56, the radiated heat at average rate of heating was found to be 10 per cent of the total combustion heat, or $10 \times 1097/993 = 11$ per cent, when referred to the lower heating value of natural gas. This value holds for radiation in the open air. In a hot furnace, effective radiation is reduced by counter radiation from the walls. The temperature of the burner cup is estimated to be 3400 F. For a furnace temperature of 2200 F, radiation is reduced to $\left[1 - \left(\frac{2200 + 460}{3400 + 460}\right)^4\right] \times 11 = 8.6$ per cent. The products of combustion leave the furnace at 2400 F and carry with them 60 per cent of the combustion heat, referred to the lower heating value. The heat delivered by burner radiation then equals $8.6/40 = 21.5$ per cent of the heat released in the burner and left in the furnace.

These calculations are somewhat crude; they also neglect gaseous

[2] *Industrial Heating*, 1949 and 1950; also ASME paper 50–A–59, presented at the annual meeting, 1950.

radiation in the furnace. However, they suffice to prove that the term "radiant gas burner" must not be taken too seriously.

The Capacity of Gas Burners. The capacity of gas burners is commonly expressed in cubic feet of fuel gas per hour. Actually, the cross-sectional areas of the burner must be large enough to pass not only the fuel gas but also the necessary air. But what is "large enough"? Volume flowing in unit time equals cross-sectional area times velocity. A high velocity results in a small burner, but it requires a high head pressure of gas and of air. A low velocity calls for a big burner for which the head pressure can be small. Between the two extremes lies a range within which small changes in size of burner make very little change in burner operation. Within this range, most of the burner makers keep the velocity on the high side, not only for the above-mentioned reason but also because a high velocity imparts direction to the flame and produces turbulence, which, in turn, makes for a more uniform furnace temperature. In Chapter IV, reasons are given for the fact that low velocities reduce formation of scale. However, few builders and prospective purchasers of furnaces consider reduction in scale formation important enough to spend additional money for large burners.

The makers of burners have laboratory facilities and do not offer their burners for sale until they have been tested. The capacities that are printed in their catalogues can be depended upon to be correct.

From this fact it might appear that further discussion of burner capacity would be superfluous. There are, however, problems that are not answered by a perusal of catalogues; they include blowoff velocity, flashback velocity, attainable head pressure, and still others.

The velocity at the furnace end of the burner tile is a good standard of comparison. For an average rate of heating, that velocity, based on cold air and cold gas, ranges between 40 fps and 70 fps. The actual velocity is higher, the excess depending upon the place where combustion began. The velocity is not uniform either, being high in the center and low at the circumference. Size of the burner is responsible for the range in average velocity. At the entrance to the burner tile, nominal velocities are usually much higher.

The prospective purchaser of gas burners is interested in the "turndown," which is the ratio of the highest possible rate of firing to the lowest trouble-free rate of firing. Beyond the highest rate, the flame is blown off the burner tile. Below the lowest safe rate, flashback occurs in premix burners and the flame crawls back into the nozzle of nozzle-mix burners. Flashback occurs whenever the velocity of flame propa-

gation exceeds the velocity of flow of the explosive mixture in any section that is exposed to heat. The velocity of flame propagation is a function of several variables. Among them are (1) composition of fuel gas, (2) ratio of fuel gas to air in mixture, (3) temperature of fuel and air mixture, (4) size of duct through which mixture flows, and (5) temperature of duct through which mixture flows.

Many test data on velocity of flame propagation have been published. They run uniformly like this (in feet per second): Producer gas, 1.25; methane, 1.2 to 2; carbon monoxide, 1.4; carbureted water gas, 2.2 to 2.5; water gas, 2.5 to 4.5; coke-oven gas, 5.5; and hydrogen, 9. These values rise with higher temperatures. The flame velocity of rich gases grows with the square of the absolute temperature. It is, therefore, important to keep the passages through which explosive mixtures flow cool; the velocity of flow is smallest along the walls, and time is, therefore, available for absorbing heat from the walls. The effect of size of duct or passage has not been sufficiently emphasized in the past. An explosive mixture will burn at a slow rate in a ½-in. pipe. The same mixture will explode, when filling a 30-in. pipe; the speed of the resulting shock wave exceeds the velocity of sound. In his book "Wärmetechnische Rechnungen für Industrie Öfen," Werner Heiligenstaedt published values of flame velocities found from his own experiments. For coke-oven gas his values are (freely adapted from metric dimensions):

Diameter of Pipe, in.	Flame Velocity, ft/sec
1	20
2	33
3	39

The measuring of velocities is notoriously difficult, especially so in a burner that discharges into a furnace. The difficulty was circumvented by the makers of gas burners in the following manner: For each burner, a definite relation exists between velocities and pressure drop through the burner. This statement is true for premix burners and for nozzle-mix burners. If, on a test stand, a burner is operated for some time at rated capacity and is then fed more gas and air by raising the pressure ahead of the burner, a pressure is reached at which the flame is blown out if the burner is tested in the open, and is blown away from the burner tile if the burner is tested in conjunction with a furnace. Conversely, if the head pressure is gradually reduced, a low pressure is reached at which the flame flashes back in premix burners, or burns in the nozzle of a nozzle-mix burner.

Makers of burners keep the rating of their burners below the blowoff flow, and base the rate of turndown on a flow that is in excess of the flashback flow. The latter is not given in burner catalogues, because it varies with furnace temperature and with the arrangement of the burners in the furnace.

The effects of size of burner and of type of fuel on flashback pressure and on blowoff pressure are exhibited in Table VIII. The tabulation is based on tests that were made by the Surface Combustion Corporation. Tests made with burners of a different make would most certainly produce different values. However, Table VIII proves that experiments and demonstration tests should be made before a new burner is put on the market.

TABLE VIII*

Rated Input, 1000 Btu/hr	Flashback		Blowoff	
	Manufactured Gas	Natural Gas	Manufactured Gas	Natural Gas
45	1.0 in.†	0.2 in.	0.5 psi	1.0 in.
130	2.5 in.	0.6 in.	0.9 psi	6.0 in.
290	4.5 in.	1.0 in.	1.0 psi	8.0 in.
410	5.5 in.	1.0 in.	1.2 psi	30.0 in.

* H. Schramm, *Steel Processing*, March and April, 1947.
† In. = inches of water column.

The "blowoff" mixture pressure varies within wide limits, depending upon the design of the burner. A very high mixture pressure is required for blowing the flame out of the cup of the burner illustrated by Figs. 55 and 56. The highest useful mixture pressure is, of course, always smaller than the blowoff pressure. With nozzle-mix burners, there is no mixture ahead of the burner. The separate pressures of gas and of air takes the place of mixture pressure (ahead of the burner tile).

If gas and air (separately or mixed) are put under pressure by a pump, which may be of the displacement type or of the centrifugal type, any desired pressure may be obtained. If pressure is generated by inspiration (jet action) as in the illustrations Figs. 52 and 53, the obtainable pressure is limited. The jet of gas imparts velocity to the air. The kinetic energy of the mixture is converted into mixture pressure, and the mixture pressure in turn is converted back into kinetic energy of flow in the burner. The double conversion is not always practiced. In the burner of Fig. 58, for instance, a true mixture pressure cannot develop. The divergent section builds up just enough pressure to move the mixture into the furnace against furnace

pressure. If several burners are served by a single inspirator, a true mixture pressure is built up. Such an arrangement is illustrated diagrammatically in Fig. 63. Although the inspirator in Fig. 63 is not part of the furnace, a brief discussion of its action is in order.

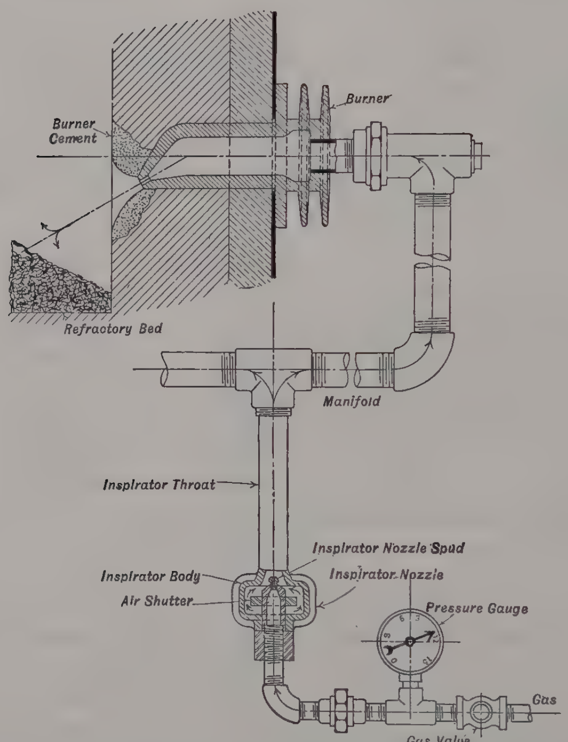


FIG. 63. High-pressure inspirator. High-pressure gas is the inducing medium.

The momentum equation is fundamental for inspirators: Mass of driving fluid × velocity of driving fluid + mass of driven fluid × velocity of driven fluid = mass of mixture × velocity of mixture. "Mass" here means mass flowing in unit time. The equation is correct if pressures at inlet and discharge are equal. Since the driven fluid arrives with a negligibly small velocity, the equation becomes

$$\text{Velocity of (gas plus air) mixture} = \frac{\text{Mass of driving fluid} \times \text{Velocity of driving fluid}}{\text{Mass of (gas plus air) mixture}}$$

If the mixture velocity could be converted, without loss, into pressure,

the mixture pressure would equal $\frac{\text{velocity}^2}{335 \times \text{specific volume}}$, inches of water column, see Vol. I, 4th edition, page 403.

While these two equations do not take care of friction forces, they are accurate enough to permit the drawing of some conclusions, such as the following: A rich gas, for instance natural gas (which requires a large volume of air per unit volume of gas), must be delivered to the inspirator at a much higher pressure than is required for a leaner gas, such as coke-oven gas. The leaner the fuel gas, the easier it is to obtain a high mixture pressure.

The complete equations of the inspirator jet pump are fairly complicated. They also involve friction coefficients that vary with design and with smoothness of surfaces. For that reason most of the makers of inspirators made tests in their laboratories and laid their experiences down in either tables or charts. Figs. 64 and 65 are charts that were furnished by the Mid-Continent Metal Products Co. In Fig. 64 the inclined lines indicate the gas pressures that are needed for obtaining mixture pressures (vertical scales) as a function of the calorific value of the gas and of the size of the inspirator. The latter variable is read from the horizontal scale at the top.

Fig. 64 confirms the conclusion that a high mixture pressure is most easily obtained if the driving fluid is a low-Btu gas. The same illustration also reveals that, with a given gas pressure, a higher mixture pressure can be obtained in large inspirators than can be obtained in small inspirators.

The values of Fig. 64 are test results that were obtained with a given make of inspirator. Other inspirators have different proportions and different smoothness of surfaces. For such inspirators Fig. 64 is only an approximation. In spite of this fact, the chart of Fig. 64 is very useful, because it clearly shows the relations between the variables.

The chart of Fig. 65 furnishes some information on the size of inspirator that is needed for a given capacity. From the gas pressure (marked on the inclined lines) and from the capacity in Btu per hour (vertical lines, scales at top and bottom of chart), an intersection point is determined. Following horizontally, from that point to the kind of gas used, furnishes the size of the gas spud (both in Morse twist-drill units and in $\frac{1}{64}$ in.) and also the pipe thread at the discharge end of the inspirator. This information suffices for selecting the correct inspirator from the catalogue. Again, the chart would have to be modified for inspirators of another make.

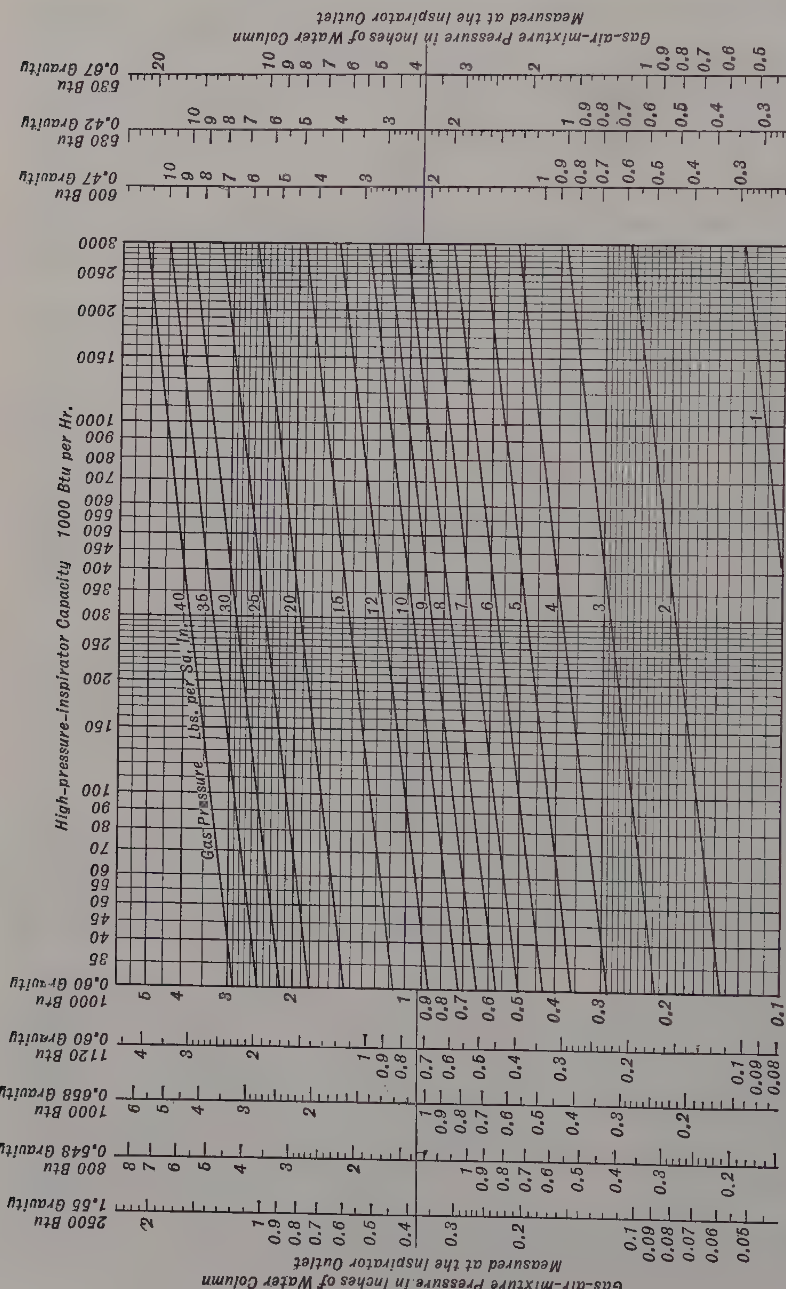


FIG. 64. Chart for computing the gas pressure which is necessary for obtaining a given mixture pressure. Courtesy of Mid-Continent Metal Products Co.

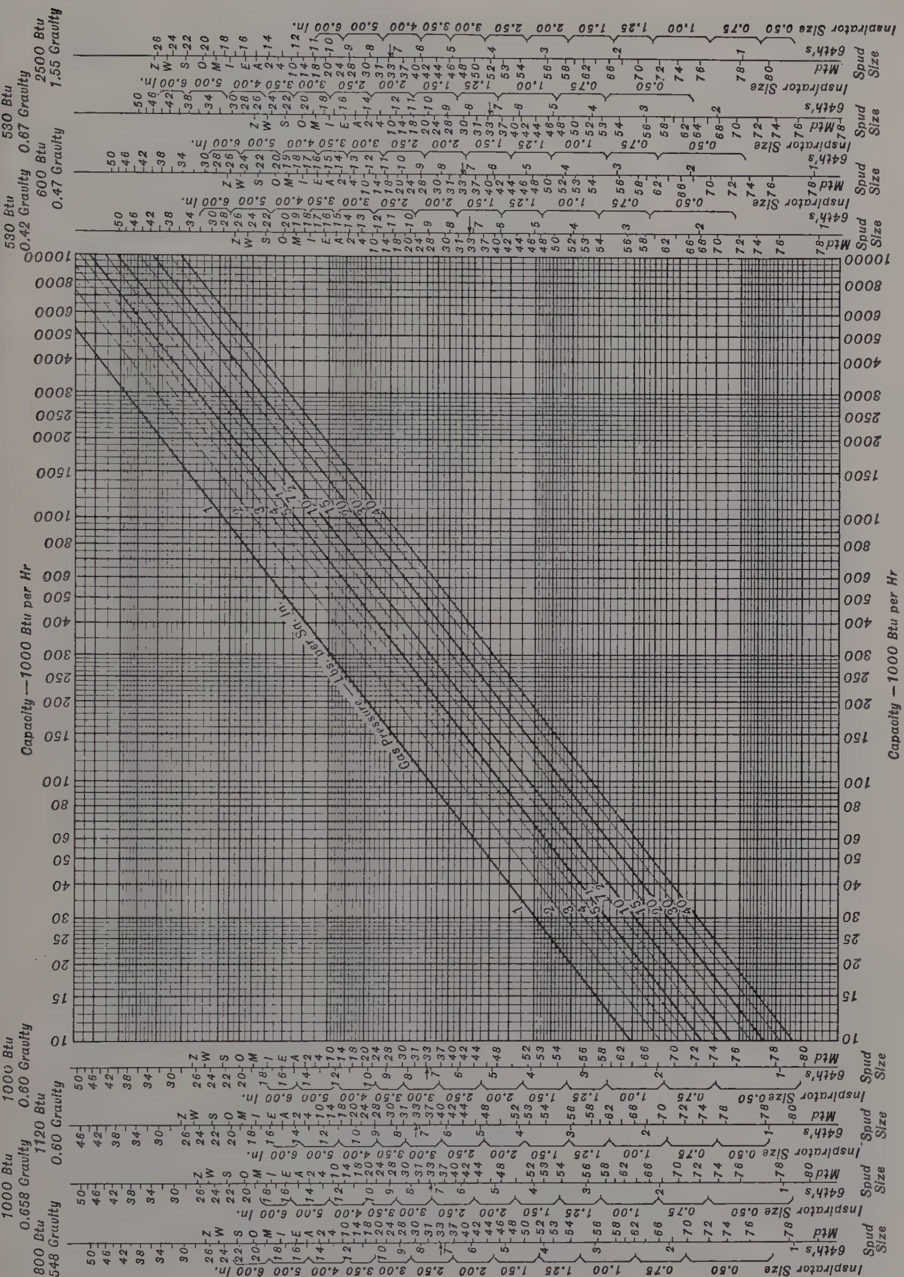


FIG. 65. Chart for computing size of high-pressure inspirator. Courtesy of Mid-Continent Metal Products Co.

Example. An inspirator with a capacity of 350,000 Btu/hr is to be selected for natural gas having a heating value of 1000 Btu/cu ft and a specific gravity of 0.658. The available gas pressure is 25 psi. In Fig. 65, follow the ordinate halfway between abscissae 300 and 400, to inclined line for gas pressure 25 psi, which has to be interpolated between 20 and 30 psi. From the intersection follow horizontally to the type of gas available. The answer is a number 41 Morse twist-drill spud, and a 2½ in. thread at the discharge end of the inspirator. From Fig. 64 the mixture pressure for the here assumed conditions is found to be 2.7 in. of water. The burner port must be designed to suit this pressure.

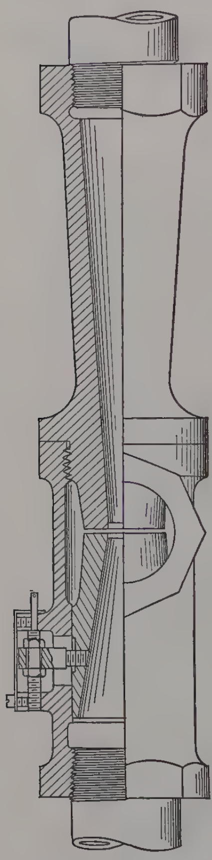


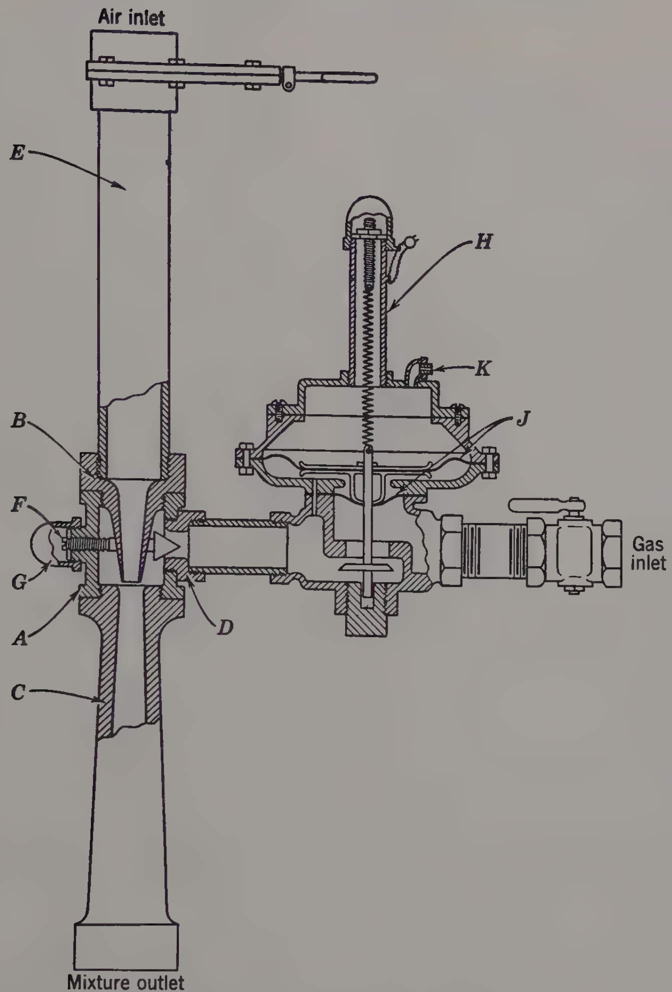
FIG. 66. Proportional mixer. Air flowing through the Venturi tube aspirates gas through the slit at the throat.

If the combustion air is the driving fluid and fuel gas is the driven fluid, the apparatus is called a "proportional mixer." The weight of air flowing is so great when compared to the weight of commercially used rich gases that inspiration can easily produce a reduction of pressure (partial vacuum) in the throat of a Venturi tube. Figs. 66 and 67 are sections through proportional mixers. Although they look different, they are based on the same principle. Fuel gas passes through a "zero governor" (which is shown in Fig. 67) and enters the mixer at atmospheric pressure. Air-to-gas ratio is adjusted by axial movement of the inlet cone in Fig. 66, and by a cone valve in Fig. 67.

Calculation of flow is based on available air pressure, the momentum equation, and on partial recovery of pressure in the slender divergent tube.

Proportional mixers never serve individual burners; they discharge into manifolds which serve a plurality of burners.

Successful operation of furnaces which are served by proportional mixers or high-pressure inspirators is predicated upon correct design and pressure drop between mixer mouth and burner port. Although elbows and tees are good mixers, they produce friction which, if high enough, will seriously interfere with the rationing ability of the mixer. To avoid such interference, the manifold (that is, mixture-piping) friction must not exceed 25 per cent (20 per cent is better) of the static pressure at the outlet of the proportional mixer. Formulae and charts for pipe friction are given in all engineering handbooks. Their appli-



A = suction or mixing tee; B = air jet; C = Venturi sleeve; D = gas orifice; E = air straightener; F = gas-ratio adjuster; G = adjustment cover or acorn; H = zero gas governor; J = diaphragms; K = breathing hole.

FIG. 67. Proportional mixer and zero governor. Courtesy of Eclipse.

cation to manifold calculations has been very noticeably simplified by the development of Fig. 68, which, while only an approximation, furnishes results that are sufficiently correct for practical purposes. The chart is based on the following facts: Practically all commercial fuel gases, when burned with air in correct proportion, deliver approximately 100 Btu per cu ft of combustion air. Hence $\frac{\text{Btu}}{100 \times \text{hour}}$

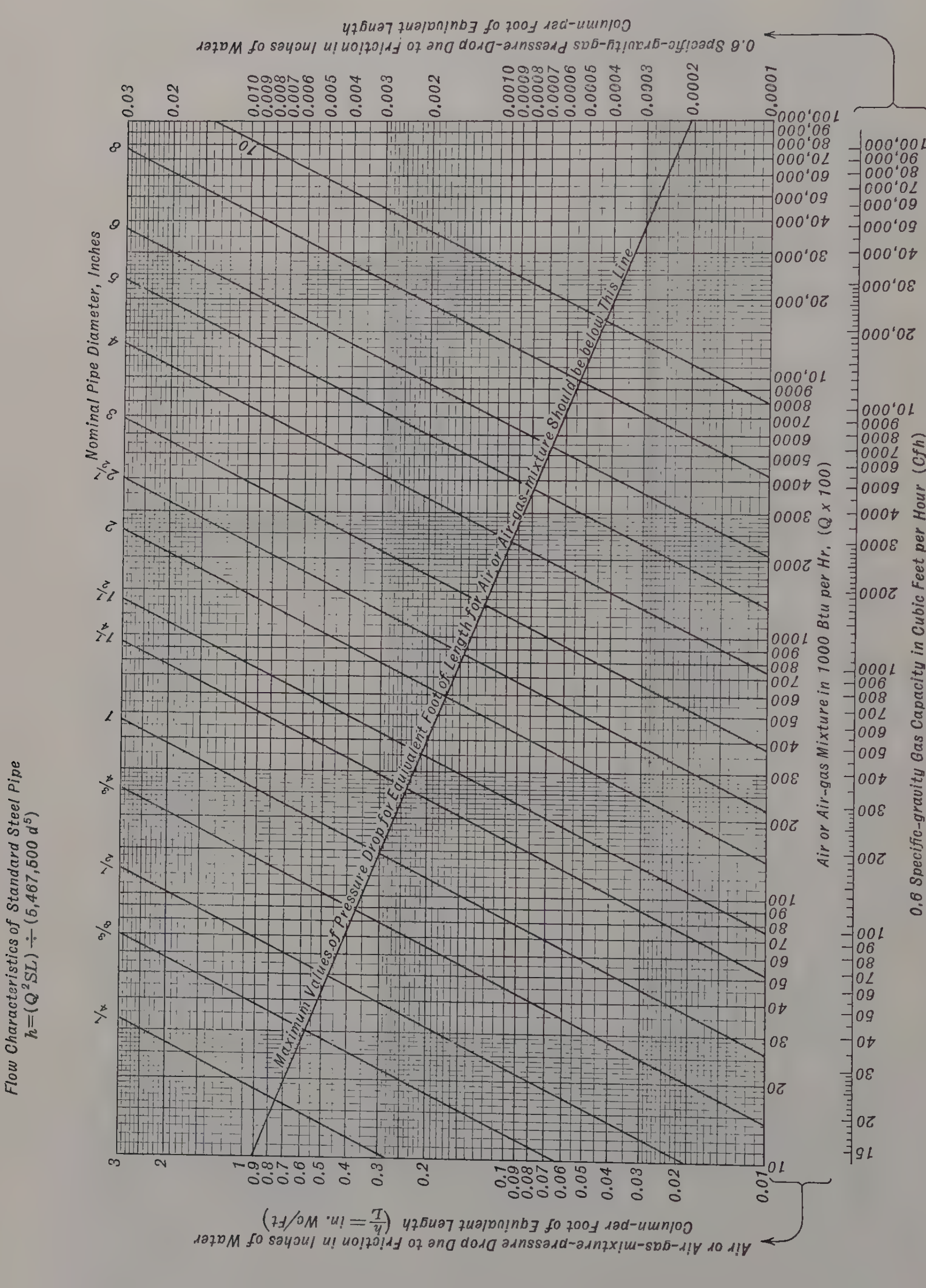


FIG. 68. Chart for computing friction in burner manifolds and pipes

is approximately the volume of air flowing per hour. Furthermore, practically all commercial fuel gases when burned with air in correct proportion deliver between 96 and 104 Btu per cu ft of gas-air mixture. Hence $\frac{\text{Btu}}{100 \times \text{hour}}$ represents the flow of gas-air mixture without serious error.

Temperature conditions higher than the 60 F standard usually compensate for the errors. In the chart, Fig. 68, the pressure drop in inches of water per foot of pipe length is given as ordinate. Two scales are available. The one on the left is to be used in conjunction with the horizontal scale which reads in 1000 Btu per hr. The one on the right is to be used in conjunction with the horizontal scale which reads in cubic feet per hour. If, for example, a gas-air mixture which delivers 1,000,000 (1000 $\times$ 1000) Btu per hr flows through a 4-in. pipe, the pressure drop is 0.018 in. of water per ft of length.

In manifold piping, fittings account for a large part of the pressure drop. Therefore they must be considered in the calculation. This consideration is made easy by the use of Table IX, which furnishes that length of pipe which produces the same pressure drop as the fitting, both being of equal nominal diameter. In the example given above, a 4-in. standard elbow would produce 11 $\times$ 0.018 or 0.198 in. of water-column drop.

Combustion Devices for Liquid Fuel

Preparation of Fuel for Combustion. Oil or tar seldom burns as a liquid; usually it is the oil or tar vapor which burns, because the kindling temperature of the liquid lies far above its vaporization temperature.[3] If an attempt is made to burn liquid oil, the vapor of the oil burns at the surface just as fast as it can combine with the available oxygen. If, on the other hand, an oil vapor is formed and is mixed with air, combustion is a mass action.

The light oils (distillates) can be burned as received. The heavier residual oils and tar, especially topped tar, must be heated before they reach the burner. The heating equipment includes a steam-heated coil in the tank car, a similar coil in the underground storage tank, a pump with an auxiliary heater, and a heating pipe in contact with the oil pipe all the way to the furnace. This auxiliary equipment is not part of industrial furnaces and is not described in this volume.

[3] In Diesel engines, atomization is so extremely thorough, air and fuel mixture is so intimate, and air temperatures as well as pressures are so high that a large part of the oil burns in the liquid phase.

TABLE IX

Equivalent Length of Valves and Fittings in Feet of Pipe of Same Diameter

Pipe size	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	4	5	6	8	10
Blast gate open	0.35	0.46	0.6	0.8	0.93	1.2	1.4	1.7	2.3	2.8	3.5	4.6	5.7
Long sweep elbow or on run of standard tee	0.8	1.0	1.3	1.7	2.0	2.5	3.0	3.8	5.0	6.2	7.5	10.0	13.0
Medium sweep elbow or on run of tee reduced in size $\frac{1}{4}$	1.3	1.8	2.3	3.1	3.6	4.7	5.4	6.8	9.1	12.0	14.0	18.0	22.0
Standard elbow or on run of tee reduced $\frac{1}{2}$	1.6	2.2	2.8	3.7	4.4	5.3	6.4	8.2	11.0	14.0	17.0	21.0	26.0
Tee through side outlet	3.7	4.6	5.6	7.5	9.1	11.0	14.0	17.0	22.0	28.0	33.0	43.0	57.0
Globe valve open	17	22	27	37	43	57	65	83	112	140	165	225	280
Close return U bend	3.6	5.0	6.2	8.5	11.0	13.0	15.0	18.0	24.0	31.0	36.0	48.0	62.0
Teapot-tee side outlet reduced $\frac{1}{2}$	2.6	3.4	4.2	5.6	6.7	8.1	10.2	12.6	16.5	21.0	25.0	32.0	42.0
Pipe bushing smaller diameter $\frac{d}{D} = \frac{1}{2}$	0.6	0.8	1.0	1.3	1.5	1.8	2.3	2.9	3.8	4.8	5.6	7.5	10.0

For a thorough understanding of the necessity for fine subdivision of the oil stream and mixing of the droplets with air, the following facts must be considered. Fuel oil consists of molecules each of which contains many atoms. They are easily cracked by heat; while being cracked, they pass through the stage of having carbon mixed with partly cracked residue. Long-chain molecules, having many carbon atoms, are also formed. If this mixture strikes solid surfaces in the absence of sufficient air for hydroxilation (combustion to CO and H_2O with some H_2 left), a carbonaceous, coky mass is built up which interferes with the flow of furnace gases and finally clogs up the furnace unless it is removed from time to time. If walls are far away from the burner, subdivision and mixing need not be extremely good; but if the distance from burner to wall is short, finest subdivision and excellent mixing are very necessary. The Diesel engine is an extreme illustration for the latter statement.

Moreover, tar and the heavy fuel oils contain residues which cannot be vaporized and which require a long time for combustion (see below under Combustion Devices for Powdered Coal). They should likewise be kept from contacting furnace walls because they aggravate the building up of coke.

Quick combustion, completed before the partially burned products have a chance to come in contact with solid walls, is secured by very fine subdivision of the fuel and quick, thorough mixing of fuel vapor and air. Combustion is quickened still more if the combustion air is highly preheated.

In accordance with these properties of liquid fuel, we find several methods of preparing it for combustion, namely:

1. Vaporization.
2. Atomization.
3. Combination of vaporization and atomization.

Before each classification is taken up, a few wise words from an experienced furnace engineer (Mr. A. J. Fisher) may well be interjected:

> The most important element in the design of an oil-burning system is the furnace. Its shape, hearth area, volume, and combustion chamber are most important. The furnace must be a compromise between the requirements of the material to be heated and the oil-burning equipment.

Vaporization. Distillate (light) oils can be vaporized without being cracked. They were produced by vaporization; distillation is vaporization that is followed by condensation. It must, however, be realized that temperature is controlled very closely during the distillation

process, whereas that same close temperature control is impossible in vaporization previous to combustion. There is always a place where overheating occurs at some time. Overheating results in cracking and in deposits of carbon, which eventually clog the passages. Furnace operation is then interrupted until the clogged ducts have been cleaned.

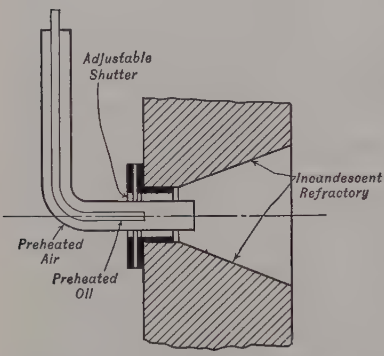


FIG. 69. Vaporizing burner for light oil and preheated air.

For these reasons, vaporization of oil has been used only sporadically in connection with industrial furnaces. But every once in a while an optimistic furnace engineer concludes that he can vaporize a distillate oil without cracking it. Fig. 69 illustrates such an attempt. Preheated oil, the flow of which is controlled by a valve, flows through a pipe that is surrounded by preheated air. At the entrance to the burner tile the oil is intended to have reached vaporization temperature. The intention was to heat the oil to a temperature somewhere between 400 and 550 F. The stream of hot oil, partly vaporized, and partly ready to flash into vapor, flows into a current of very hot air. The mixture flows through an ignition tile into a combustion chamber which is surrounded with glowing refractories and in which vaporization, as well as combustion, is completed.

The combustion method illustrated by Fig. 69 is simple, but has very serious disadvantages. At the time of starting with a cold furnace, there is no vaporization, and the heating is slow, smoky, and inefficient. Occasional overheating of the oil in the delivery tube causes carbonization and clogging. The design has disappeared from the American market, but will probably bob up again in the future as a brand-new invention. The burner of Fig. 69 has an additional fault when serving an industrial furnace. Secondary air through the shutter will flow into the burner tile only when there is draft (partial vacuum) in the furnace. In metal-heating furnaces a draft is not permissible.

Reference is here made to page 24, where a vaporizer for oil is described and illustrated. This vaporizer is principally used for short periods, namely, on the few very cold days when the supply of natural gas is either curtailed or interrupted. The vaporizer is cleaned when not needed.

Atomization. Practically all the important burners on the market are based on *atomization* or, as it is sometimes called in British literature, *pulverization*. These terms signify a fine subdivision of the oil or tar. Let it be repeated that atomization is only a means of quick vaporization and quick mixing of fuel with air, before the carbon particles have a chance to come in contact with solids. Atomization is followed by vaporization and mixing with air, the third step being combustion. The three steps, (1) atomization, (2) vaporization and mixing, and (3) combustion, overlap to such an extent that no sharp division can be drawn between them, but they are physical realities nevertheless.

The word "vaporization" is used here for want of a more descriptive word. Any oil that is heated to 850 F or higher before it is combined with oxygen is cracked. Residual oils crack while being evaporated. During the cracking process carbon particles are formed. They become brightly incandescent and impart a characteristic brilliancy to oil flames and tar flames.

After the oil has left the spray tip of an atomizer, which breaks it up into very small droplets, it is mixed with air in a burner tile, from which it passes into the combustion chamber. The burner tile receives radiant heat from the combustion chamber, heats the oil, and vaporizes a large part. Finally, such a temperature is reached that every drop has been completely vaporized, or the remainder has been broken up into the elements, carbon and hydrogen. The combustion of these elements completes the burning of the liquid fuel. Although in the combustion of gaseous fuels speed of combustion practically coincides with speed of mixing, another factor enters with liquid fuels, namely, fineness of atomization and rate of vaporization. Everything else being equal, the smaller the drops, the more rapid are its heating and partial vaporization; from this statement it follows that atomization is a vital factor in the efficient burning of oil or tar, particularly if only a limited space is available for combustion. The heavier (more viscous) the fuel, the greater is the importance of atomization.

For a thorough understanding of the physical facts in the combustion of liquid fuel, Fig. 70 is offered. The upper part represents, in a diagrammatic fashion, the burner and burner tile, whereas the lower part indicates velocities. Going from left to right, we find increasing velocities of flame propagation (because of better mixture and higher temperature) and decreasing velocities of flow (because of the cone angle of the burner tile). At the point of intersection of the two velocities, combustion begins. It is not necessary to know exactly what the velocity of flame propagation is; the flaring of the burner

tile takes care of variations and insures stability of flame front. For this, and other reasons, the flaring burner tile is used more often than the cylindrical burner tile. (See Fig. 71.) In the cylindrical burner

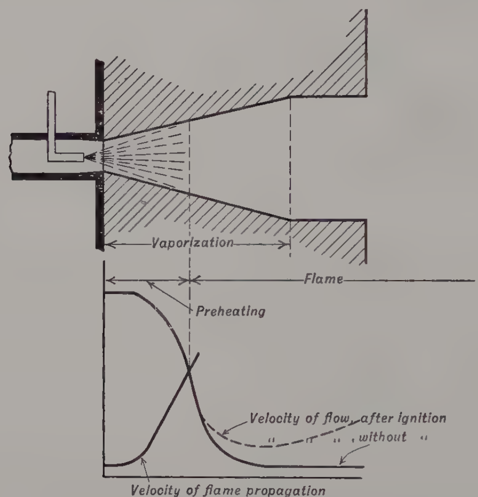


Fig. 70. Variation of velocities in a burner tile. Note that combustion begins where velocity of flame propagation equals velocity of air-and-oil mixture.

tile there are eddy currents which, when the furnace is cold, mix cold products of combustion with fuel-air mixture and cause fluttering combustion or even blowing out of the flame. Moreover, the cylin-

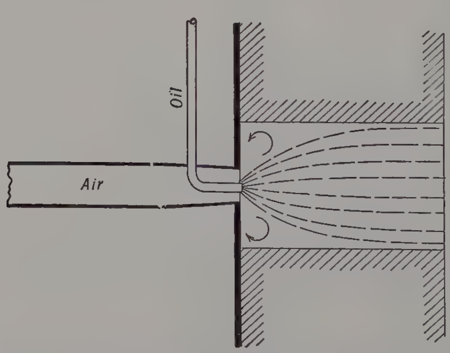


Fig. 71. Eddy currents in a cylindrical passage in a burner tile.

drical tile does not offer a definite place at which ignition begins. Cylindrical burner tiles also cause difficulties in starting. With highly preheated air, no burner tile is necessary; neither is it neces-

sary with extremely fine atomization. For these statements, the Diesel engine is a good example. For very heavy oils, such as No. 6, a burner tile has been recommended which consists of a steep cone followed by a cylindrical section. Such a tile is shown in Fig. 72.

Occasionally a refractory tip (Fig. 73, item 1) is arranged at the end of the burner tile, where it acts as an additional mixing and combustion help. The tip has been found useful if either oil or air or

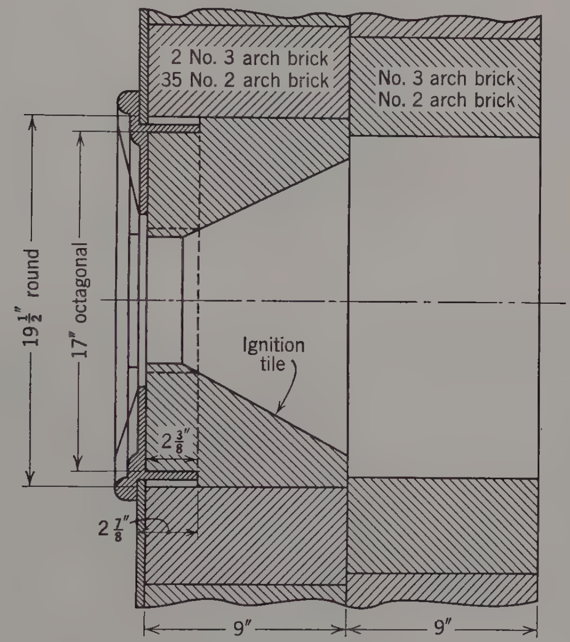


FIG. 72. Burner tile with conical and cylindrical sections.

both arrive in a pulsating flow which tends to extinguish the flame. The tip is also useful if atomization and mixing are poor. The tip deflects the flame away from the charge and directs it along the roof. This is an advantage in low furnaces with poorly mixing burners. The opening above the tip is made wide horizontally.

In the combustion space of underfired furnaces refractory blocks, as shown in Fig. 74, are common. These blocks split the flame and cause a more uniform temperature in the very hot combustion space than would prevail without them. The piers also support the hearth. Locating the blocks is quite an art.

In the atomization of a liquid fuel, mechanical work is required to overcome the cohesion, or molecular attraction, of the liquid. Al-

though the amount of this work is unknown, it certainly has some relation to the viscosity and the vapor pressure of the oil or tar. At

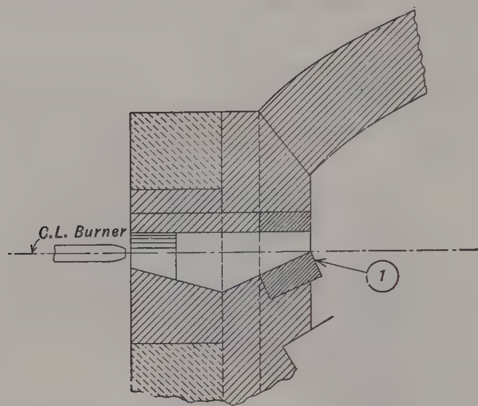


FIG. 73. Burner port with refractory ignition tip.

the vaporization temperature, the cohesion is zero. From this reasoning it follows that liquid fuels should be heated as high as considerations of safety and correct burner operation permit. Raw tar is heated to 160 or 170 F; at higher temperatures the more volatile portions of the tar flash into flame and, moreover, the flame sputters. Topped tar is heated to 250 F. Heavy oils are heated to 180 F or higher, if the nature of the oil permits, without too much carbon being deposited. Lower temperatures are suitable for lighter oils; an oil of 36 to 40 Baumé (Nos. 1 and 2) can be atomized very well at room temperature. If the oil temperature is too high, the lighter constituents of the oil flash into vapor in the burner mouth, where the pressure is reduced, and produce irregular sputtering of the flame.

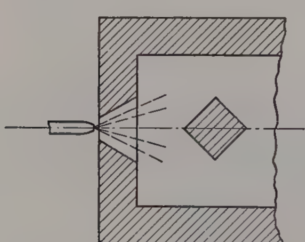


FIG. 74. Plan view of refractory block in path of flame, for insuring ignition and for spreading the gases.

Classification of Atomization. Atomization is accomplished by two methods:

1. Pressure atomization, in which the liquid is placed under pressure and is forced through a small orifice.

2. Swift-current atomization, in which velocity is imparted to the liquid (oil or tar) by a stream of air or steam that flows at a high velocity.

Many atomizers make use of both methods. The effect of both methods is the same, namely, a great difference of velocity between the oil and the surrounding air or other gas. In method 1, the oil has the high velocity. In method 2, the air or steam has the high velocity. As a result of the great difference of velocity the oil drops are flattened so much that surface tension causes the drops to break up into smaller drops. In consequence, high pressure of oil and high velocity of air or steam produce good atomization.

In atomization by fuel pressure (which is commonly referred to as mechanical atomization) the work of atomization is done by the pressure energy of the liquid fuel, whereas in steam or air atomization, the work is performed by the kinetic energy of the gaseous medium (air or steam). It is interesting to compare the work requirements of the two systems. Although we do not know the actual amount of work required to overcome the forces of cohesion, we can obtain comparative figures on the basis that the same degree of atomization will result from equal differences of velocity between oil and air (or other gases.

Although in modern Diesel engines extreme shortness of combustion time and smallness of combustion space compel engineers to work with oil pressures in excess of 10,000 psi, the oil pressure for atomization into an industrial furnace seldom exceeds 150 psi. Let us take 120 psi for calculating an example. To atomize 1 cu in. of fuel requires 120 psi times 1 cu in., or 120 in.-lb, or 10 ft-lb. The velocity of the oil drops is found from the equation: Velocity (ft/sec) $= 8.02 \times \sqrt{h}$, where h equals the height of a column of oil that exerts a pressure of 120 psi. Since 27.6 in. of water column exert one psi, the column of oil that exerts a pressure of 120 psi equals $27.6 \times 120/(12 \times 0.9) =$ 307 ft, where 0.9 is an average specific gravity of oil. The velocity of the oil drops equals $8.02\sqrt{307} = 139$ ft/sec.

In swift-current atomization the atomizing effect is the same if the air (or the steam) impinges upon the oil with a velocity of 139 ft/sec. There exists, however, one important difference. In mechanical atomization, each droplet is subdivided by the resistance of a gas that is at rest or is moving slowly. In swift-current atomization it is not at all certain that each particles of air or steam meets an oil drop and is thereby used for atomization. The pressure that is needed for producing an air velocity of 139 ft/sec is very low. It is found from the equation: pressure (in. of water) $= 0.118 \times 139^2/530 = 4.3$ in. of water column. (See equation 42 of Volume I.) This pressure is so low that all of the combustion air must be utilized for atomization. Since 1 volume of oil requires roughly 10,000 volumes of air, the atom-

ization work per cubic inch of oil equals 10,000 cu in. $\times$ 4.3 in. of water $\times$ 0.036 psi/in. of water = 1550 in.-lb = 130 ft-lb. This represents the theoretical minimum.

If oil is atomized by compressed air or steam, a very low figure for the quantity of air used is ⅓ lb of air per lb of fuel. Since 1 cu in. of oil weighs 0.03 lb, the weight of compressed air per cubic inch of oil equals 0.01 lb. Hence the minimum power requirement for compressed air is $pv \times \log_e$ (ratio), where p equals absolute pressure of air, v equals specific volume at pressure p, and $\log_e$ (ratio) equals the logarithm to the base e of the pressure ratio. If air at 90 psi pressure is used, the ratio is $\frac{90 + 14.5}{14.5}$, which equals 7.2. Then the work in foot-pounds per cubic inch of oil equals:

$$0.01 \times 14 \times 14.5 \times 144 \times \log_e 7.2$$

which equals 575 ft-lb. If the losses in the compressor are taken into account, the work will exceed 650 ft-lb.

It is very obvious that pressure atomization (mechanical atomization) requires by far the smallest amount of power, as far as atomization alone is concerned. This advantage of pressure atomization is, however, not as great as would appear from the figures for work requirements. In order to insure a steady supply of uniformly heated oil at all burners, it is necessary to pump two to five times as much oil as is atomized in unit time; the excess work is dissipated in the regulating valve which returns the oil to the sump. Besides, the mixing of oil and combustion air requires power. This phase of the problem will be discussed later.

Pressure Atomization. Various forces are used to produce mechanical atomization. They will now be enumerated.

1. If an oil drop moves with extremely high velocity through comparatively still air, the effect is just the same as if fast-moving air passed over an oil drop: Fine shreds of the oil are torn off the drop by the friction between the air and the oil, and the oil drops are flattened and split into two or three smaller drops. Atomization, or formation of an oil fog, results.

2. If a fine stream passes through a sharp-edged orifice, in a conically enlarging orifice plate, the particles marked 1 in Fig. 75 do not lose their lateral velocity, and a mild amount of atomization results.

3. If the oil is heated under pressure, it does not flash into vapor as long as the pressure is greater than the vapor pressure of the oil.

In the orifice, the pressure is relieved, some vapor is formed, and the oil is scattered by the "explosion." This action is very effective in producing atomization.

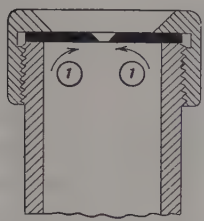


FIG. 75. Atomizer with simple flat-plate orifice.

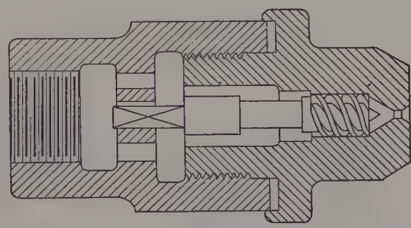


FIG. 76. Centrifugal atomizer for producing cone-shaped spray.

4. If the oil is given a rotary or whirling motion (for instance, by a screw thread, as indicated by Fig. 76) just before it reaches the orifice, each particle has, upon leaving the orifice, a tangential component of motion. In consequence, the oil leaves in a cone-shaped spray, each droplet being torn to pieces, because particles in the same droplet have different tangential directions.

Pressure (mechanical) atomization is favored, if the rate of firing is reasonably constant, as in marine boilers. If applied to industrial furnaces, mechanical atomization has several disadvantages. Regulation of the quantity of oil atomized in unit time requires variation of the oil pressure at the orifice, because variations in the size of orifice or the exchange of one orifice for another of different size cannot be accomplished in industrial furnace work. Dropping the pressure to one-half the maximum value lowers the oil quantity, in unit time, to about 70 per cent of the maximum value and results in less perfect atomization. If oil is shut off, radiation from the hot furnace cokes the oil in the burner tip and makes it inoperative.

Another disadvantage which applies to small unit burners only is the small size of the orifice. A tip with a $\frac{1}{25}$-in. diameter hole passes 200 lb of oil (almost 30 gal) per hr with 200 psi pressure.[4] A hole $\frac{1}{50}$ in. in diameter passes 50 lb per hr with the same pressure. But liquid fuels, such as residue fuel oil or tar, carry minute solid particles of coke, silt, or slush; and the chances of clogging the burner

[4] With properly heated oil, the quantity discharged in unit time through an orifice can be computed with sufficient accuracy from the everyday formula of elementary hydraulics because the viscosity of the heated oil is too low to affect the result perceptibly.

tip increase rapidly as the size of the orifice is reduced. Even distillates contain solid particles such as bits of packing material from the oil pumps. Care is, therefore, needed in the selection of oil strainers and filters.

Burners with mechanical atomization by high oil pressure are in successful operation on a few large heating furnaces. Good atomization at reduced rates of firing is accomplished by the principle of making the oil whirl rapidly even at turndown. The oil is whirled as in other atomizers, but a large part of the oil does not pass through the atomizing orifice; it is returned to a pump. The principle of an atomizer of this type is illustrated by Fig. 77. These atomizers are known as wide-range atomizers, because the centrifugal force of the whirling oil produces good atomization even at partial rates of firing. If wide-range atomizers are applied to large industrial furnaces, means must be provided for blowing the atomizers empty when the furnace is being shut down.

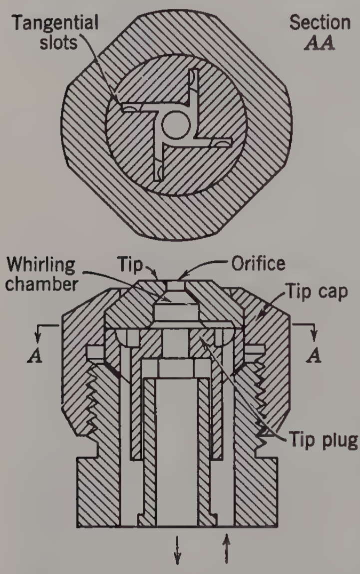


FIG. 77. Wide-range pressure atomizer.

Swift-Current Atomization. Atomization by means of steam or compressed air employs two forces: (*a*) the expansive force of the atomizing agent, as it is released from high pressure, and (*b*) the shredding, slicing, or shearing and subdividing action which it exerts upon the liquid while the fluid travels at a high velocity. Two systems are in use:[5]

1. High-pressure atomization.
2. Low-pressure atomization.

In the first system, air or steam of 60 to 125 psig is used; whereas in the second system, air up to 2 psig serves the purpose.

As to the preference between steam and air as atomizing agents,

[5] In England the following classification is commonly used:
High-pressure air, 5 psig and upward.
Medium-pressure air, 1½ to 5 psig.
Low-pressure air, ¼ to 1½ psig.

steam costs less than compressed air, wherever high-pressure steam is used for other purposes or is generated in a waste-heat boiler. On account of the reaction $C + H_2O = CO + H_2$, steam produces a less luminous flame than air does. Air produces a hotter and shorter flame, because it sustains combustion, whereas steam is ballast.

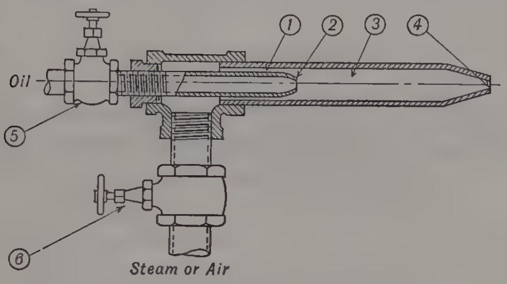


FIG. 78. Simple high-pressure atomizer.

A steam atomizer is illustrated in Fig. 78. Oil, 2, and air or steam, 1, mix in 3, where the oil is emulsified. The ratio of fuel to atomizing medium is adjusted by valves 5 and 6. In 3, the pressure is several pounds per square inch greater than atmospheric pressure. In the nozzle, 4, a second atomizing action takes place. The atomizer of Fig. 78 is easily made from pipes and standard pipe fittings. It is a great favorite for home-made burners, in spite of the high consumption of steam or air. Atomization is often imperfect with this burner; the fuel drops are large, because fuel falls to the bottom of space 3 and is blown over the lower edge of nozzle 4. This nozzle is often flattened for the purpose of obtaining a flat spray.

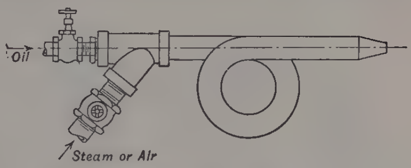


FIG. 79. Simple atomizer with mixing loop.

The mixing of oil and steam is improved by obstructions in the discharge pipe, 3, or by a coil as shown in Fig. 79. Centrifugal force throws oil to the top and reduces the drooling.

A more refined design of this general type is shown in Fig. 80. The steam consumption rises from 1½ lb per gallon of oil at rated capacity to 5 lb per gallon at 15 per cent of rated capacity. Atomizers of this type are often used for regenerative and for recuperative furnaces. In these atomizers oil pressure and steam pressure must be kept con-

stant, preferably by sensitive pressure-reducing valves. Variation of either pressure changes the nature and the length of the flame very noticeably.

As previously pointed out, it is important to bring *all* of the atomizing medium into intimate contact with the fuel. Fig. 81 shows a good method of approaching this goal. A number of Venturi tubes

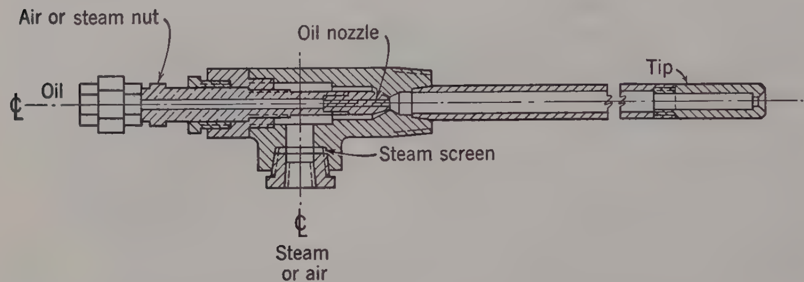


FIG. 80. Emulsion-type burner. Courtesy of Bloom Engineering Co.

lie around the circumference at the discharge end. Oil flows from the inside into each throat, while air or steam flows at high velocity through each throat. At that place, the pressure of the atomizing medium has been reduced; however, that pressure is still considerably higher than atmospheric pressure. In consequence, oil must be deliv-

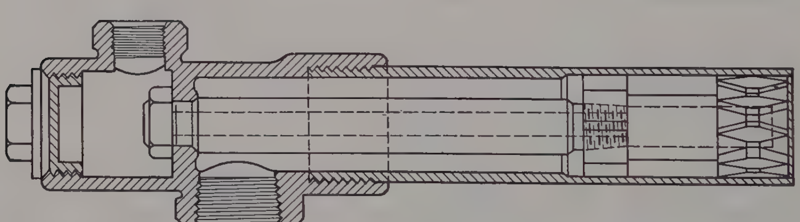


FIG. 81. High-pressure atomizer on the Venturi principle. Courtesy of Hauck Mfg. Co.

ered to the atomizer under pressure. For light oils, this pressure lies between 5 and 25 psig; for heavy oils it lies between 25 and 35 psig. If steam is the atomizing medium, it must be either superheated or dry saturated. Hot water does not atomize.

The field of applicability of the atomizer of Fig. 81 is the same as it is for the atomizers shown in Figs. 78, 79, and 80. These atomizers are used more with furnaces of other types than they are for industrial furnaces. Atomization by steam is limited to large works, where

steam is available for other purposes. Steam is available whenever heavy residue oils are burned, because steam affords the best method of heating oil and tar. In smaller works, in which light oil serves as fuel, compressed air is the atomizing medium. At a pressure of 70 psig, about 150 cu ft of free air are needed for atomizing at rated capacity of atomizer, and much more at partial turndown. This is about 10 per cent of the air that is required for combustion.

Oil Burners. Up to this point, no oil burners have been described or discussed; the discussion was limited to atomizers. These atomizers are often called burners, because they are inserted into streams of preheated air. The port for preheated air plus the atomizer form the burner. As a rule, matters are different with the so-called low-pressure burners. All of the combustion air passes through the burner.

The term "low-pressure burner" is vague. It covers air pressures from ¼ psig to 2 psig. The air velocities caused by these pressures have such a range that different methods of atomization are required. A pressure of ¼ psig causes an air velocity of 175 ft/sec, whereas a pressure of 2 psig imparts a velocity of 500 ft/sec to the air (at 70 F). Air flowing at 175 ft/sec requires almost three times as much cross section as is needed by air flowing at 500 ft/sec. In consequence it is more difficult to make the oil come in contact with all of the air. This fact has led to a difference in design. At 2 psig air-pressure atomization is usually completed in two stages, whereas three stages are used with pressures of ½ psig or lower.

A perfect oil burner performs three functions:

1. It atomizes the oil.
2. It mixes oil mist and air.
3. It proportions the flow of oil and of air.

The high-pressure atomizers accomplish only item 1, that is to say, atomization. Most of the low-pressure burners also mix oil mist with air. Very few burners maintain a constant oil-air ratio. The proportionate flow of oil and air is discussed in Chapter IV.

In low-pressure burners, as in all atomizers, it is important that the velocity of the atomizing air be kept up at turndown. To this end the air passages must be reduced when the flow of oil is reduced. Taking care of this requirement leads to complications in burners that work with triple atomization.

Some power can be saved by compressing less air than is required for combustion and by inducing the rest. This method cannot be recommended for industrial furnaces because it requires manipulation of air registers (or shutters) for maintaining the correct fuel to

air ratio, and such manipulation is never done correctly. Since induction of air is permissible in other furnaces, Fig. 82 is offered. It shows the fraction of combustion air that is needed for atomization, as a function of pressure of atomizing air. Curve *B* is a practical average. Curve *A* represents the rock-bottom minimum that can be obtained with good design, in which all of the atomizing air impinges upon the oil.

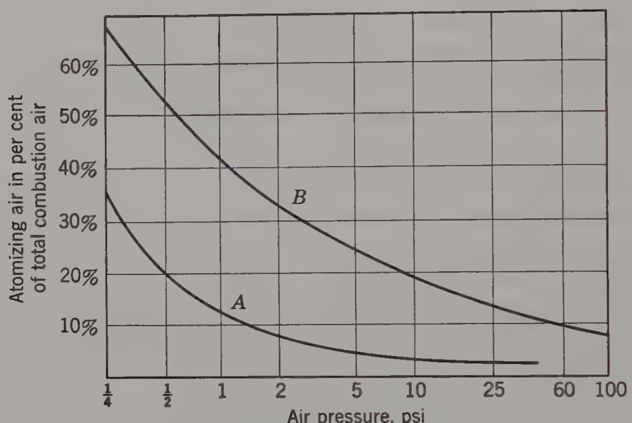


Fig. 82. Fraction of total air required for atomization as a function of air pressure. Curve *A* shows the theoretical minimum; curve *B* furnishes practical values.

A few examples will illustrate the state of the art with regard to good atomization and thoroughness of mixing. These examples should not be construed as being the best that is obtainable in the market. Other designs that embody the same principles, but in a different form, are equally good (or bad).

With an air pressure of 2 psig and good design, atomization in one stage suffices, especially for the light oils. The residual oils cannot be made as fluid as the light oils, in spite of having been heated. For that reason, they are often delivered to the atomizer at a pressure of 70 psig. From earlier explanations it is known that oil pressure assists in atomization. Fig. 83 is a good example of single-stage atomization by air of 1½ psig and by oil of 75 psig. Incidentally, the illustration tells how to change the length of the flame by a different design of air nozzle. Burners of the type shown in Fig. 83 are recommended for furnaces with an almost constant rate of heating.

Most of the 1½ psig burners are designed for two-stage atomizing and mixing. An example is the "reverse blast atomizer" that is illus-

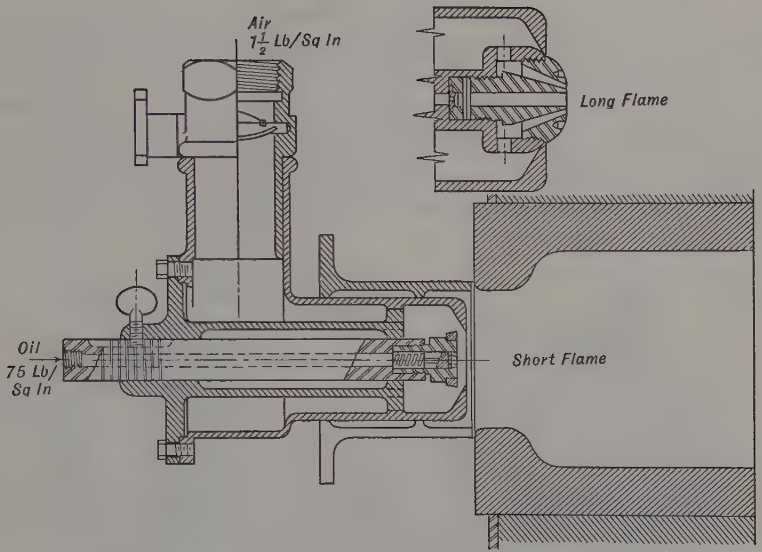


FIG. 83. Burner with low-pressure air. Note interchangeable tips for changing length and shape of flame.

trated by Fig. 84. Unless controlled by a blast gate, the primary supply of atomizing air is constant, regardless of the rate of firing. The secondary atomizing air is manually adjustable by the handle shown at the left.

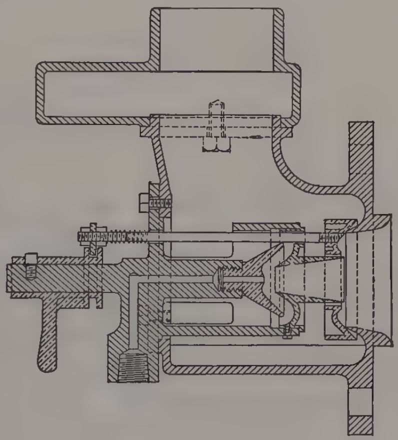


FIG. 84. Reverse-blast atomizer.

Truly low-pressure burners are usually designed for triple atomization. It is quite difficult automatically to adjust the flow of three streams of air for constant velocity. The following examples are proof for this statement. In Fig. 85, oil oozes or squirts (depending upon the rate of firing) out of radial holes, 2, into whirling air which enters tangentially through holes, 1. The air-oil mixture is met by more air coming from slot 5, which is adjustable by sleeve 7. The sleeve is operated by a handle, 9, which is guided by a cam slot. Primary and secondary air coming from 3 passes to 1 and 4. Tertiary air coming from 8 penetrates into the air-oil mixture near slot 6.

Slot 6 is not adjustable, which means that the tertiary air must be adjusted by a valve in line 8, which may carry preheated air. Primary air is not adjustable either.

None of the burners described thus far keep the air velocity constant (and proportional to the flow of oil) when the rate of oil delivery is changed. The principle of a burner that does both is illustrated in Fig. 86. The lever that increases the flow of oil also pulls back the

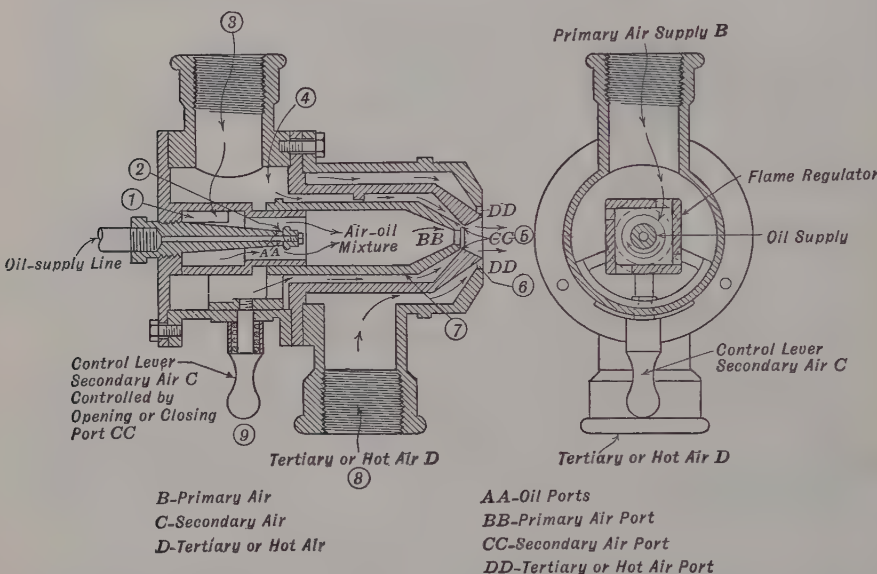


Fig. 85. Atomizer with triple atomization.

sleeve that surrounds the oil delivery tube. The passages for both primary and secondary air are enlarged by this movement. Oil delivery and size of air passages are interconnected by a cam (shown in dotted lines near the center of the burner) of such a shape that the flow of oil and the flow of air are proportional, as long as air pressure, oil pressure, and oil temperature remain constant. Although commercially in the low-pressure range, this burner is not strictly of the low-pressure type. It is intended for 1 to 1½ psig air pressure and for 25 to 35 psig oil pressure. The burner under discussion is a combination burner for oil and gas. Fuel gas passes through the control valve at the bottom and enters the burner tile through the outer cone, which directs the gas into the air stream. Several modifications of the oil nozzle are on the market.

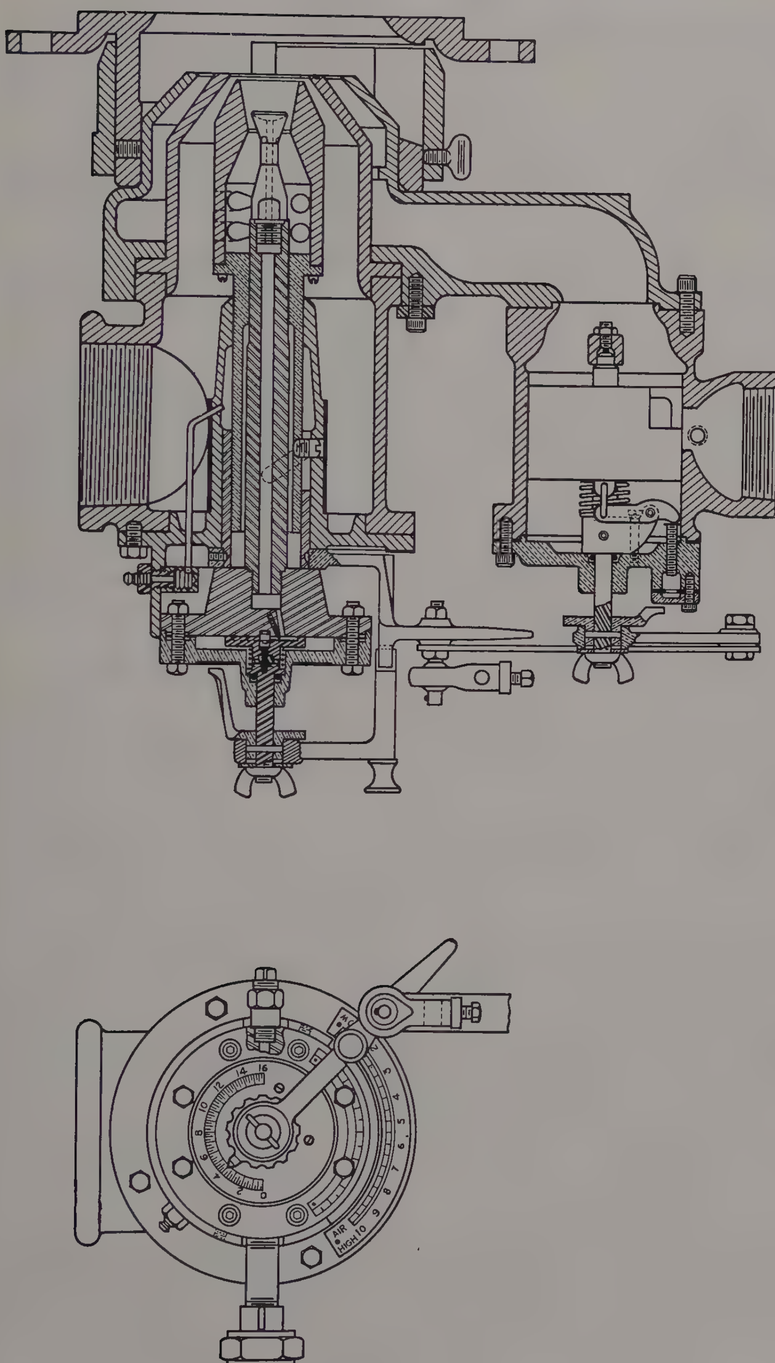


FIG. 86. Oil burner with constant velocity of atomizing air and with proportionality between oil flow and air flow. Courtesy of Hauck Mfg. Co.

Capacity of Oil Burners. It is often required to ascertain approximately the capacity of a given oil burner or to design a new burner for a given capacity. The method of making these calculations is shown in the following example.

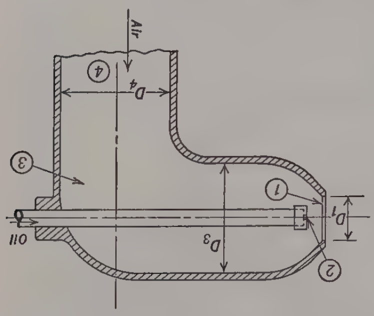


Fig. 87. Diagram of simple form of low-pressure burner.

An oil burner is to have a capacity of 10 gal of oil per hr at 40 to 50 psi oil pressure, 12 oz per sq in. air pressure. What size of air nozzle, of air inlet, and of oil openings is required?

For the purpose of this example a very simple and idealized type of burner will be considered, as shown diagrammatically in Fig. 87. It does not represent the best practice in burner design, which fact is evident from a study of the preceding pages. The burner shown in Fig. 87 was selected for this example on account of its simplicity. The same principles of calculation apply, of course, to the more complicated burners.

The calculation will be begun on the assumption (which will later be dropped) that 70 per cent of the combustion air passes through the burner and that 30 per cent passes around it by induction. The calculation is based on an air pressure of 12 oz (¾ psig). Total air required

$$= \frac{10 \text{ gal/hr} \times 6.75 \text{ lb/gal} \times 14 \text{ lb air/lb oil} \times 13.2 \text{ cu ft/lb air}}{60 \text{ min/hr}}$$

= 209 cu ft/min, if no excess air is supplied

70% × 209 cu ft/min = 147 cu ft free air/minute required at 12 oz pressure

The velocity of air at ordinary temperatures, corresponding to a pressure drop of 12 oz per sq in., is approximately:

$$c = \sqrt{64.4 \times \frac{12 \text{ oz}}{16 \text{ oz/lb}} \times 144 \times 13.2 \text{ specific volume}}$$

$$= 303 \text{ ft per sec}$$

On account of the shape of the nozzle usually employed in oil burners, the air jet will contract somewhat, giving a discharge coefficient of about 0.85.

Then: $0.85 \times A_1 \times 303 = 147/60$ cu ft per sec. Solve for A_1.

$A_1 = 0.0095$ sq ft, area of outlet,

and $D_1 = 1.32$ in., or approximately $1\frac{5}{16}$ in., diameter of nozzle opening

With oil heated sufficiently for atomization, the viscosity is too low to affect the flow through orifices to a noticeable extent. Assuming the flow to be reduced even as much as 10 per cent below that of a perfect fluid, the size of the oil hole, 2, is found from the equation:

$$\frac{10 \text{ gal/hr}}{60 \times 60 \times 7.48 \text{ gal/cu ft}} = \frac{A_2}{144} \times 0.90 \times 0.62 \sqrt{\frac{45 \text{ lb/sq in.} \times 64.4 \times 144}{50 \text{ lb oil/cu ft}}}$$

where $0.62 =$ contraction coefficient. Solve for A_2.

$A_2 = 0.00105$ sq in.; from which $d_2 = 0.0365$ in., diameter of oil opening.

Next, suppose that $\frac{1}{2}$-oz air-pressure drop is allowed, to take care of the resistance of the right-angle bend at 3 and of the velocity head at entrance 4. The bend resistance is approximately equal to the velocity head; hence each is $\frac{1}{4}$ oz.

$$\text{Velocity corresponding} = \sqrt{64.4 \times (\tfrac{1}{4} \times \tfrac{144}{16}) \times 12.5}$$
$$= 43 \text{ ft per sec}$$

(12.5 = specific volume of air at 62 F and 12 oz air pressure)

$$A_4 = \frac{\frac{12.5}{13.2} \times 147 \text{ cu ft/min} \times 144}{60 \times 43 \text{ ft/sec}} = 7.8 \text{ sq in.}$$

from which $D_4 = 3.15$ in.

A standard 3-in. pipe could be used, giving a slightly greater loss, $\frac{5}{8}$ oz per sq in., instead of $\frac{1}{2}$ oz per sq in.

If all of the combustion air is to pass through the burner casing, its linear dimensions will have to be $\sqrt{100/70}$ ($= 1.19$) times as great as those found from the preceding calculation. In that case $D_1 = 1.19 \times 1.32 = 1.57$ in., and $D_4 = 1.19 \times 3.15 = 3.75$ in.

The calculation shows clearly that the dimensions of the burner are determined, not by the size of the oil openings, but by the size of the air passages. The overall size of the burner shown is determined by the diameter D_4. If it were desired to use this burner for twice the quantity of oil, a new tip could easily be placed on the oil tube, with an aperture of twice the area, but the air opening could not be appreciably increased without providing an entire new casing. On the other hand, if the air required for the double quantity of oil were to be forced through a $1\frac{5}{16}$-in. diameter opening, the pressure required

would be 48 oz, or 3 psi, which is excessive. Furthermore the velocity would be too great, and would blow the flame away from the burner.

Again, if the air were preheated to 400 F, the air-outlet diameter (for 10 gal of oil per hr) would have to be increased to 1⅝ in., if the same pressure of 12 oz per sq in. were used.

In this connection, the pressure-volume characteristic of an average centrifugal blower should be taken into consideration. Such a blower can deliver more than the rated volume of air, but only against a lower pressure. In the present case, the blower would be required to deliver more air against a higher pressure. A bigger casing and a larger blower would be needed.

In summary, then, the dimensions of an oil burner are determined, not by the quantity of oil, but by the quantity of air which it must supply, and a given size of burner cannot be used satisfactorily to burn a greater quantity of oil than that corresponding to the quantity of air which it will supply under the pressure for which it was designed.

At this point, the objection may be raised that the burner mouth, A_1, has to pass not only air, but also partly vaporized oil. However, the distance from the spray nozzle to the mouth is so short that a negligible fraction of the oil is in vapor form.

Troubles with Oil Burners. One of the most troublesome features of burners for liquid fuel is the carbonization (coking) of the fuel in the burner and the clogging caused by it. This is due, in a large measure, to the fact that the burner tip is at all times exposed to the radiant heat of the combustion chamber. This same backradiation is also the reason why the burners with mechanically rotated atomizers cannot be used with industrial furnaces. If preheated air is used, the burner receives additional heat from the air-blast pipe which surrounds the oil pipe.

Several methods are in use for minimizing the danger of carbonization: The burner tile is made long and no larger at the air entrance than necessary. Low-pressure burners, which use a large fraction (or all) of the necessary air for atomization, are well protected by the constant flow of cold air. Burners with mechanical atomization and with preheated blast air are in greatest danger of carbonization, particularly at light loads. In burners of that type, it is customary to surround the oil pipe, 1, Fig. 88, with an insulating jacket, 2, through which circulation of atmospheric air takes place or in which a small flow of compressed air is maintained. This air is discharged at the tip. A burner with a supply of cold air and of preheated air is illustrated in Fig. 85. In that burner the oil orifice is so far removed from the burner tile that coking cannot occur.

The danger of coking is greatest immediately after a shutdown. The radiant heat of the hot furnace is then transmitted back to the body of the burner. Several means exist for eliminating coking at such times. An air connection may be provided for blowing the oil out of the tip. Or a drain valve may be installed for draining the oil in the burner. A combination of these two methods is the safest. If the main shutoff valve is not tight, the drain valve reveals that fact. Burners that fire vertically downward are self-draining. Burners firing through the roof have given a very uniform heat. They are, however, seldom installed, because of difficulties of attendance.

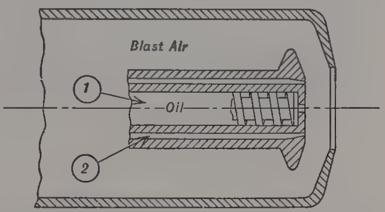


FIG. 88. Burner for use with preheated air. *Note:* A jacket of flowing cold air protects the oil from the hot blast air.

Many troubles with oil burners have their origin not in the burners, but in the auxiliary equipment. These troubles may stem from heaters in the storage tank, from pumps, strainers, too long a line of cold oil, wet steam for atomizing, and so on.

The lighting up of oil burners is discussed in Chapter VII.

Combination Burners for Gas and Oil. In many localities of the United States, natural gas is cheaper than fuel oil, on a Btu basis. Natural gas is also more easily controlled and is free from sulphur. However, it is diverted, either partially or wholly, to domestic consumers on very cold days. Butane, propane, and casing-head gasoline are occasionally used as fuels on those days; their use is ordinarily limited to furnaces of small or medium size. For large furnaces, light oil is the most frequently used stand-by fuel.

In the early days of the art, the gas burners were removed on cold days and were replaced by oil burners. The change-over from gas to oil and back again was expensive in several ways. This fact stimulated the design of combination burners in which the change-over can be accomplished quickly, solely by the manipulation of valves. Many combinations of gas burners and of oil burners are possible, but practice has narrowed them down to a few types. Two types are in use. In the less expensive burners, either gas or oil is burned. In the more expensive types of burners, both fuels can be burned simultaneously. The advantage of the latter arrangement is that gas and oil can both be burned on days when the gas supply is curtailed, but not interrupted.

In most of the combination burners, the pressure of the atomizing

air ranges between 1 and 2 psig and the oil pressure ranges between 15 and 20 psig. Combination burners are apparently not built for preheated air. Fig. 89 illustrates a burner that has a wide application. From the drawing it appears that atomization is not as fine as it is in straight oil burners made by the same manufacturer; however, that does not matter for the few days of operation on oil. Moreover, only light oil is used in these burners. The illustration is so well marked that no other explanation is required.

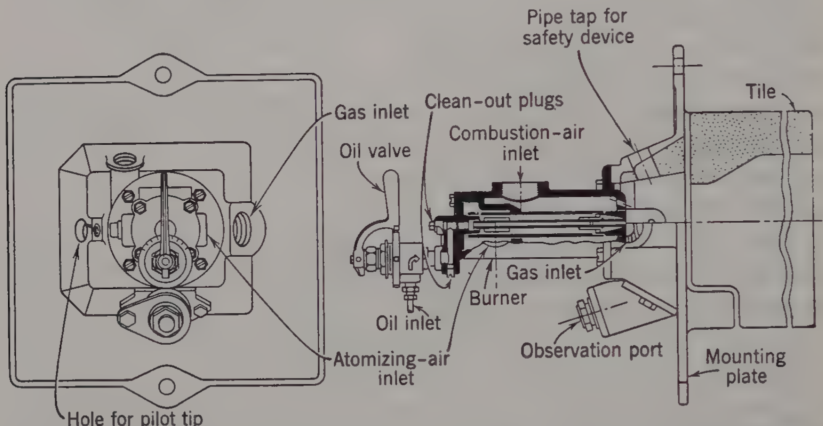


Fig. 89. Combination gas-and-oil burner. Courtesy of North American Mfg. Co.

The combination burner of Fig. 86, already referred to, has a good atomizing device and also good mixing arrangements for air and fuel, for gas as well as for vaporized oil. Proportionality of flow of fuel and of air exists at all rates of firing, with either fuel or both fuels.

Devices for Burning Coal or Coke

Although coal is the most widely used fuel, its use in industrial furnaces has decreased greatly since the first edition of this book, and it has done so in spite of the fact that coal is the cheapest fuel on the market. The situation is paralleled by the motor car, in which coal is not used either, for obvious reasons.

In 1920 many coalfired industrial furnaces were in use in the United States. Today, coal is almost an emergency fuel, to be used only when and where the more convenient gaseous or liquid fuels are not available. If combustion devices for coal and coke are discussed in spite of this retrogression, this is because a change in economic con-

ditions may again increase the use of coal and because, in some other countries, the more convenient fuels (which have replaced coal) are not readily available. The extreme eastern section of Canada is an example of an area without oil or natural gas and with an abundance of coal. It may also be mentioned that some ceramic furnaces are fired with coal in the United States, much to the disgust of the neighbors. These furnaces produce black smoke as long as the ware is cold.

Coal can be burned: (1) on the grate, (*a*) handfired or (*b*) mechanically fed and stokered; (2) in pulverized form.

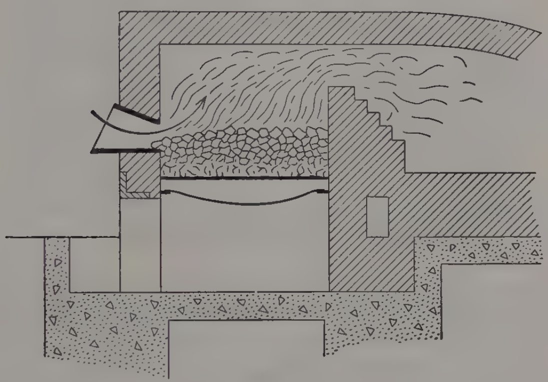


FIG. 90. Grate and combustion chamber of coalfired furnace with draft over the hearth.

In the following discussion more attention is given to bituminous coal than to any other solid fuel because it is more widely used.

Fig. 90 not only has historical value but also is an example of "how not to do it." A partial vacuum (draft) in the furnace is needed to make the coal burn. The result is air infiltration into the heating chamber and heavy scaling of the charge. Well-known but insufficient remedies are: piling up cinders outside the doors, or coal or coke inside the doors, with the optimistic hope that the oxygen in the air will combine with the carbon and not with the charge. The roof over the grate and over the bridge wall burns out quickly unless the grate is very large and the rate of burning is low. Draft in the furnace can be avoided by placing the grate much lower than the hearth. The basement is the best place. Putting the grate there results in the original Siemens furnace, with an inclined step grate and water in a pit under the grate. This arrangement is much better than Fig. 90, but it is very inconvenient to watch the heating chamber on one level and to stoke at another level.

The next step of burning coal on a grate was the development of semigas firing which is still being used today. As shown in Fig. 91, it consists of blowing a mixture of steam and air into the closed ashpit and of blowing dry secondary air into the furnace just beyond the bridge wall. Pressure in the ashpit does away with the necessity for partial vacuum in the furnace; in fact, a slight furnace pressure can be maintained so that air infiltration is eliminated. Steam, flowing

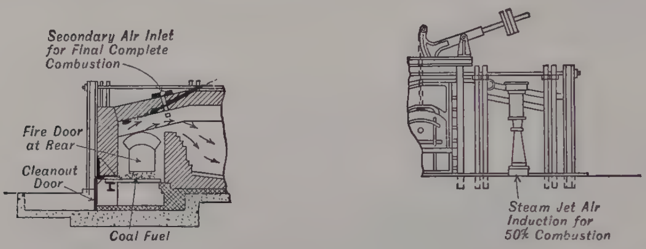


FIG. 91. Coalfired furnace with steam jet for forcing air into closed ashpit, and admission of secondary (dry) air.

conjointly with air through the fuel bed, keeps its temperature down and practically eliminates clinkering. In fact, the fuel bed has become a gas producer. This method of heating is called semigas firing. Admitting secondary air beyond the bridge wall distributes heat and combustion over the hearth. As a rule, a steamblower or ejector forces the steam-air mixture into the ashpit, while a fanblower injects secondary air.

Another method of supplying steam under the grate consists in having one blower furnish both primary and secondary dry air and in running exhaust steam from an engine or hammer into the ashpit. In the latter case a steam regenerator should be used in order to make the steam flow fairly continuous. Where no steam is available, water boxes in the sidewalls under the grate have been used. However, they are soon filled with scale. Their use cannot be recommended.

In large, coalfired furnaces, in order to obtain fairly uniform distribution of temperature throughout the furnace, it is often necessary to use several combustion chambers of moderate size, located at intervals along the furnace, rather than one very large combustion chamber. Under such conditions, if one large combustion chamber were used, with a low rate of firing, the condition of the fuel bed could not be kept uniform and great temperature inequalities would result.

Mechanical Stokers for Industrial Furnaces. The performance of any handfired grate depends upon the skill and the good will of the

fireman. He may pick out lump coal (throwing the fines aside), shovel coal regularly, slice and stoke regularly, and keep the fire at the correct thickness; or else he may shovel large quantities at long intervals, allow ashes and clinker to build up, etc. In handfired furnaces there exists not only this possibility but also that of an inrush

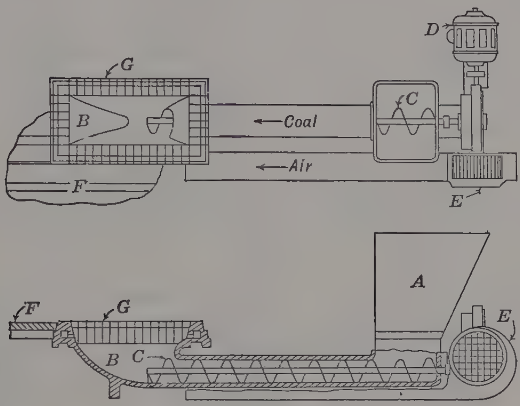


FIG. 92. Underfeed stoker with screw feeder. A = coal hopper; B = retort; C = screw; D = motor; E = fan; F = dead plates; G = tuyeres.

of cold air when the fire door is open, although this can be avoided by a proper manipulation of the dampers. Finally, hand firing necessarily involves physical labor which is not very pleasant in front of a hot furnace. For the various reasons given and because cheap slack coal can be used in mechanical stokers, the stokers deserve consideration.

Very few (if any) stokers for industrial furnaces are now being installed in the United States. The few that were installed are of the well-known, single-tuyere underfeed type with coal feeding by a screw or worm, as shown in Fig. 92, which is self-explanatory except for the fact that it does not show the dead plates on both sides of the firebox. To make the picture complete, Fig. 93 is offered. It shows the side plates and the coal spilling over on them from the firepot. Steam-laden air must be blown through the fuel bed of the stoker. Otherwise, the roof over the stoker burns out and scale forms rapidly on the charge in the furnace.

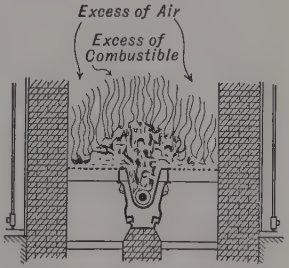


FIG. 93. Section through stoker and dead plates.

As previously stated, correctly operated mechanical stokers, when compared to hand firing, save money. Furnace owners who purchase and install a mechanical stoker often harbor the optimistic fallacy that an inexperienced man who is paid low wages can operate a stoker successfully and economically, because all the operator has to do, supposedly, is to keep the hopper filled up. They forget that, even if coal supply (by screw feed) and air supply (by fan speed or throttling valve) have been proportioned correctly, clinkers or difference in coal (ash content) will upset the ratio in time. Either the attendant must know how to restore equilibrium or an engineer must restore the equilibrium from time to time, unless the heating process is rough and does not require close adjustment of fuel-to-air ratio. The close adjustment is not required in many ceramic furnaces. As a matter of fact, most of the stokers installed in recent years are serving ceramic furnaces and kilns.

Capacity of Grates and of Mechanical Stokers. The grate area in coalfired furnaces varies between the limits of 18 per cent and 30 per cent of the hearth area. The smaller area holds for lump gas coal with low ash content.

Expressed in different terms, the required grate surface may be calculated from the quantity of fuel burned or gasified on it in unit time. Generally speaking, that area depends not only upon the quantity but also upon the quality of the coal, the size of the lumps, the volatile matter, the quantity and composition of ash, the design of the grate, and the draft. For heating furnaces, there is one additional consideration worth mentioning, namely, protection of the brickwork and of the stoker. Although it is possible to burn 75 lb of good gas coal per hour on 1 sq ft of grate surface, with a draft of 1 in. of water, the temperature of the fuel bed, resulting from so high a combustion rate, burns out the roof over the grate and over the bridge wall within a few days. For that reason, the rate of 25 lb per sq ft per hr is seldom exceeded on heating furnaces for high-temperature work; whereas, in annealing furnaces, 8 to 12 lb per sq ft per hr is an average value. It is, of course, quite possible to burn coal at a higher rate in annealing furnaces; but if this is done the grate surface becomes much too small in comparison with the hearth area and it becomes difficult, if not impossible, to secure uniformity of temperature all over the hearth. The truth of this statement will be realized from the steps which are found necessary for securing fairly uniform temperature with rates of combustion as low as 8 lb per sq ft per hr. In Fig. 94 the width of the grate is less than that of the hearth. Uniformity of temperature is obtained by a gradual widening of the

firebox in an upward direction, and by the shape of the top of the bridge wall.

The low rate of combustion which is used in connection with many handfired grates that burn lump coal has an additional advantage. The alternate streams or threads of combustible gases and excess air rise slowly and without turbulence in the combustion chamber, which, in this case, does not entirely deserve that name. When the gases pass over the bridge wall into the heating chamber, they are mixed, and a slow, sustained, secondary combustion is initiated which heats all parts of the chamber uniformly.

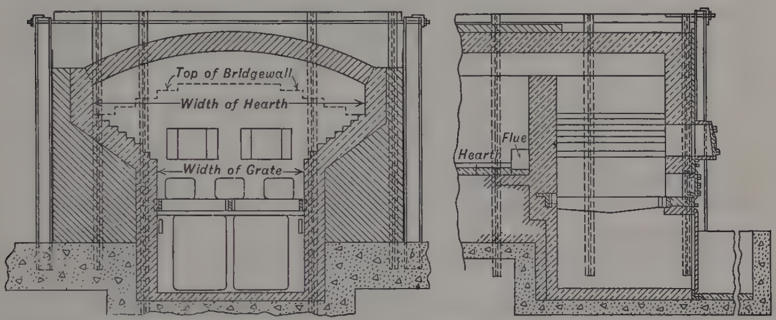


Fig. 94. Grate with gradually widening combustion chamber. Note the shape of top of bridge wall, intended to distribute the flow of gases uniformly.

Draft requirements are an important factor in determining the rate of combustion of coal on the grate. A simple relation between draft (loss of air pressure through the fuel bed) and rate of combustion would be welcomed by every furnace engineer; unfortunately, it cannot be found because thickness of fuel bed, fineness and coking qualities of coal, and conditions of the fuel bed (ashes and clinkers) influence the result to a marked degree. For that reason, the well-known tabulations purporting to give the desired relation are only a crude approximation. Nevertheless, they give some information. For that reason, one of these tables is printed below (with the above-mentioned reservations).

The draft requirements of this table were taken from grates that serve boilers (steam generators). A much higher grade of coal (large lumps, low ash) is burned on furnace grates. For that reason, the resistance to air flow is estimated to be ¼ to ⅓ of the tabular values. Using this latter information and the equations for draft as a function of temperature and vertical height (given in Chapter VI of Volume I) the vertical distance between the grate and the hearth can

be computed. For instance, if 15 lb of eastern bituminous coal are to be burned per square foot of grate an hour, the draft required above the fuel bed is 0.25×0.12 in. of water. Assume the gases above the grate to be 2000 F. Then $0.25 \times 0.12 = 7.43(1/522 - 1/2460) \times H$, from which $H = 2.7$ ft. This value agrees with practice. If a cheaper coal were used, H would have to be 11 to 12 feet. This value was correct for the original Siemens semigas producers.

TABLE X

Draft Required above the Fuel Bed in Inches of Water

Kind of Coal	Pounds of Dry Coal Burned per Square Foot of Grate per Hour						
	Rate						
	15	20	25	30	35	40	45
Eastern bituminous	0.12	0.16	0.20	0.27	0.34	0.42	0.52
Western bituminous	0.15	0.20	0.25	0.33	0.42	0.52	0.65
Semi-bituminous	0.15	0.20	0.28	0.37	0.48	0.60	0.80

If primary air is to be blown under the grate by a steam jet, the relations between draft, capacity of blower, and steam consumption can be taken from the catalogues of the manufacturers of steam-jet blowers.

In computing the rate of combustion on stokers it is customary to divide the coal burned or gasified per hour by the horizontal area of the firebox, which equals the area of the retort plus that of the side plates. If that method of calculation is followed, the rate lies between 6 lb and 32 lb per (sq ft, hr). The 32-lb rate is a catalogue rate which should not be adopted in practice because it results in a high maintenance cost owing to the burning out of tuyeres and to the excessive formation of clinkers.

An idea of the relation between rate of combustion and air pressure can be formed from the following tabulation, which refers to the type of stoker shown in Figs. 92 and 93.

TABLE XI

Rate of Combustion, pounds of coal per square foot of area of retort plus side plates per hour	5	10	15	20	25	30
Pressure in Wind Box, Inches of Water	$\frac{1}{4}$	$\frac{3}{4}$	$1\frac{1}{4}$	$1\frac{3}{4}$	$2\frac{1}{4}$	$2\frac{3}{4}$

Since pressure is applied to the ashpit of the stoker, a greater draft loss through the fuel bed is permissible than with hand firing, and a less expensive coal may be used.

Combustion Devices for Powdered Coal

In the firing of powdered coal, the properties of this prepared fuel, the feeding apparatus, the so-called burner, and the furnace, all combine and cooperate to such an extent that each item must be understood. For that reason, they are discussed separately.

Properties Affecting Combustion of Powdered Coal. Some of the advantages which gas and oil have over coal on the grate are approached by the use of coal dust. They are: inexpensive transportation of fuel to the furnaces; combustion over the hearth, which results in uniformity of temperature over hearths of considerable size; a small amount of excess air, which means smaller furnace losses by oxidation; better control of rate of combustion; and quick heating from a cold start.

The use of powdered coal involves two separate sets of equipment: One is the grinding and distributing equipment, and the other consists of the devices for feeding and for mixing the coal dust and air. Although the equipment which serves for pulverizing and distributing is extremely important for the successful use of powdered coal, a description of it does not belong in a treatise on industrial furnaces and will not be given here. It should, however, be mentioned that large furnaces are served by individual pulverizers, whereas a group of small furnaces is served by a central pulverizing plant, from which aerated powdered coal flows through a ring pipe to the furnaces. The ash in the coal dust abrades the pipes, especially at bends and tees. Abrasion has been reduced by long-radius bends and by the use of a hard metal in bends and tees. The result of the pulverizing equipment (namely, the condition of the coal dust with regard to fineness and dryness) affects the combustion as well as the deposits of ash. For that reason, these features of the grinding plant must be mentioned so far as their effect upon combustion is concerned.

By far the greatest part of our supply of coal dust (the word is used here in the sense of "pulverized coal") is made from bituminous coal, that is to say, from coal which contains a large amount of volatile matter. In the combustion of this dust, four phases occur, namely: (1) heating and drying of the dust, (2) gasification of the volatile matter and coking of the carbon, (3) combustion of gases,

and (4) combustion of the coke dust. In practice, these phases overlap to some extent.

In regular operation, heating of the dust, degasification, and ignition of the gases require a hot combustion chamber or, more correctly speaking, ignition chamber. In a cold furnace, lighted oily waste, held in the path of the coal-dust-and-air mixture for 4 to 6 min, furnishes sufficient heat for ignition with some of the burners, particularly if the coal dust is made from high-volatile coal. In many other cases, a wood, gas, or oil fire is needed for starting; while, in regular operation, the combustion of the liberated gases maintains the high temperature which is needed for quick ignition. Though ignition and combustion of the volatile matter take place quickly, on account of the diffusion of the gases, the ignition and combustion of the coke particles are comparatively slow.

As soon as the mixture of air and coal particles enters a hot combustion space, it receives heat by radiation, and this heat is absorbed quickly by the solid particles. The less air is mixed with the coal dust, the less heat is abstracted from the heated coal particles and the more quickly ignition is initiated. Obviously, if quick ignition is desired in a low-temperature furnace, it is advisable to mix only a fraction of the combustion air and to add the rest of the air in the furnace after ignition has occurred. Tests have shown that the fraction of the combustion air which should be mixed with the coal dust before injection is about 40 per cent. Evaporation of residual moisture and liberation of gases absorb an additional amount of heat before the temperature of the particle can be raised to the ignition point.

Carbon burns just as rapidly as it can find oxygen. During combustion, each coke-dust particle surrounds itself with an atmosphere of nitrogen and carbon dioxide, through which oxygen can penetrate only by diffusion or by turbulence. One volume of coke needs approximately 14,000 volumes of air under atmospheric conditions; in consequence, each particle of coke needs an air volume of twenty-four times its own diameter. For furnace conditions, the ratio of diameters grows to about 35. Within this sphere, or cube, the outer layers of oxygen must find their way to the core, where the dust particle floats. Evidently, the coke particle can find oxygen much more easily if the air sphere is small, that is to say, if the coke particle is of almost molecular dimensions. However, this condition is very far from being realized in practice. If a large portion of coal dust passes through a 300-mesh sieve, the average grain of that dust may be assumed to have a diameter of $\frac{1}{500}$ in. The surrounding air sphere

then has a diameter of $^{35}/_{500}$ in., or approximately $^{1}/_{15}$ in. This dimension is more than a million times larger than the diameter of a molecule of air. What this means in comparison with other fuels was graphically shown by Kreisinger to the ASME, 1931. Part of his illustration is shown here in Fig. 95. In consequence, the combustion of coal and coke dust follows the laws of the combustion of solids, and not of gases, in spite of the outward similarity of a gas flame and a coal-dust flame. During degasification each grain of powdered coal swells up and becomes a hollow sphere. This fact does not alter the conclusions drawn above.

Tests on the time required for the combustion of powdered coal were made by many experimenters. Fig. 96 shows combustion time as a function of diameter of coal particle. The relation is an approximation only. The various tests do not plot as a line but as a band, because of variations in composition of coal, in volatile matter, in amount and composition of ash, and in methods of supplying combustion air. It is also difficult to determine the instant when combustion has been completed. From Fig. 96 the combustion time for a particle of 0.0025 in. diameter is 0.4 sec. In order to prevent clogging, the mixture of coal and primary air should travel at not less than 40 ft/sec. Combustion of the particle is completed after a travel of $40 \times 0.4 = 16$ ft. If the secondary air is admitted at a lower velocity, the coal particle is retarded and the flame length is reduced.

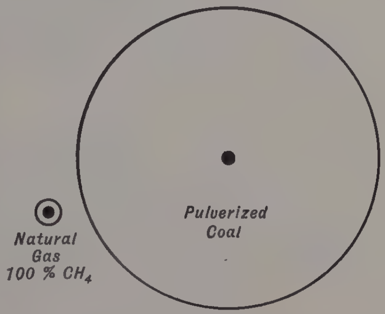


FIG. 95. Air-to-fuel volume relations for CH_4 and a coal particle.

Combustion travel can be shortened by turbulence; this fact was proved by turbulent combustion in boiler (steam-generator) furnaces. In industrial furnaces, turbulent combustion hurls ash, not against cold boiler tubes, but against sidewalls and the roof. If a furnace is built of firebrick and the ash in the coal contains iron oxide, the roof ordinarily lasts about 8 months and a much shorter time with turbulent combustion. It has also been suggested that ultrasonic vibration of considerable amplitude be impressed upon the furnace atmosphere. The vibration would cause relative motion between the gases and the coke particles, thereby quickening combustion. However, flame-travel length need not be shortened in the large furnace, and for the small furnace the vibration-generating equipment is too expensive.

In the application of powdered coal to small furnaces, two conflicting elements are encountered: Inexpensive (coarse) grinding necessitates the use of long and expensive combustion chambers, whereas the use of small and inexpensive combustion chambers necessitates expensive (uniformly fine) grinding. Coarsely ground coal damages the wall of small furnaces; and unburned particles pass out through the vent or under the door.

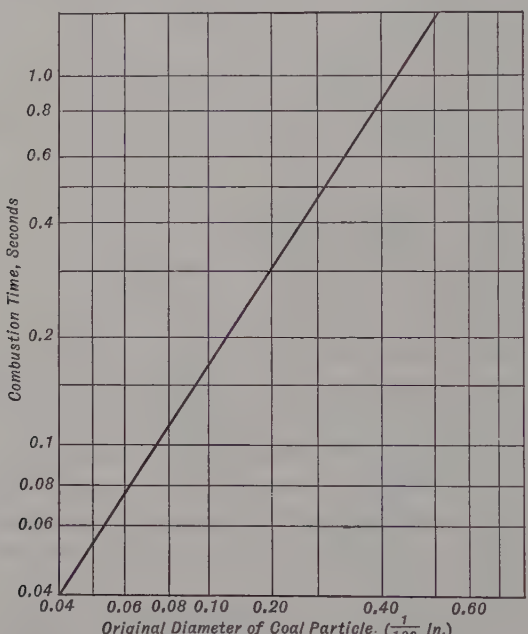


FIG. 96. Burning time of coal particles. Average of several investigators.

Many variables enter into the combustion of powdered coal, and as simple a change as the substitution of one kind of coal for an apparently similar one may upset smooth working conditions and cause trouble and vexation until the method of operation has been adapted to the new coal. This statement should not be construed to mean that only a few coals are suitable for being burned in powdered form. On the contrary, the range of coals is very wide, a greater variety of them being suitable for this purpose than for any one type of stoker. It means, however, that the practice followed in slag removal and the time between furnace repairs will vary with the nature of the coal.

Another property of powdered coal which must be considered in the

design and operation of combustion devices is its affinity for moisture; powdered coal is hygroscopic to a degree which varies very largely with the composition of the coal. Certain salts contained in the coal are very hygroscopic, and others are less so. In general, very dry coal dust flows more easily than dry beach sand, almost like water. If it absorbs moisture, it behaves like wet table salt.

The use of reasonably dry dust is advisable because damp powder (particularly with certain kinds of coal) tends to stick to the walls of the hoppers, ducts, and feeders and to form arches, thereby interfering with regular feeding. If fed immediately after grinding (without being stored), most coals do not require drying because the powder has had no time to absorb moisture from the atmosphere. Besides, it has had no time to become compacted.

Feeders for Powdered Coal. For the design of feeders, it is of importance to know that the specific gravity of newly ground coal dust ranges between 0.56 and 0.72, whereas the specific gravity of coal is about 1.2. The difference is, of course, due to the air spaces between the coal particles. If coal dust is densified or compacted by shaking, its specific gravity can be increased to 0.8 or 0.9.

Combustion devices perform the primary function of feeding the powdered coal into the furnace in a regular manner, which is subject to reliable regulation with regard to quantity; a secondary function is that of mixing the dust with air in such a manner that combustion will take place as desired.

The service which the combustion device should be capable of rendering has been aptly defined by the words "flame control." With powdered coal, feeding the dust to the furnace and mixing it with air are, in many devices, separate functions. For that reason, it will be advisable to discuss them separately, with the understanding that, in some of the devices, the two functions cannot be kept apart.

Although it has been said that dry coal dust flows almost like water, the feeding of coal from a bin at a constant (but adjustable) rate is by no means a simple matter. The rate at which powdered coal will flow through an orifice, even if the head is kept constant, varies with the dryness of the material, its state of aeration, and its fineness. All these features vary from time to time on account of the weather, wear of the grinding equipment, and the more or less irregular motion of the coal through the bin. Powdered coal fed through an orifice travels in waves or "gulps." It must, therefore, be fed by other means, which may take the form of mechanical transportation or of frictional drag of gases moving at high velocities.

In the utilization of either method, the principle is to drop the coal

dust from the hopper into the feeding device by gravity and to vary the speed or the drag of the feeding device proper within the limits required by the furnace. The design must be such that shutting down the feeder stops the flow of coal.

The great majority of mechanical feeders are either of the drum or of the worm type. Other types are used locally, but have not been generally adopted. On account of the troubles which have been experienced with the early designs of drum feeders, most experimenters

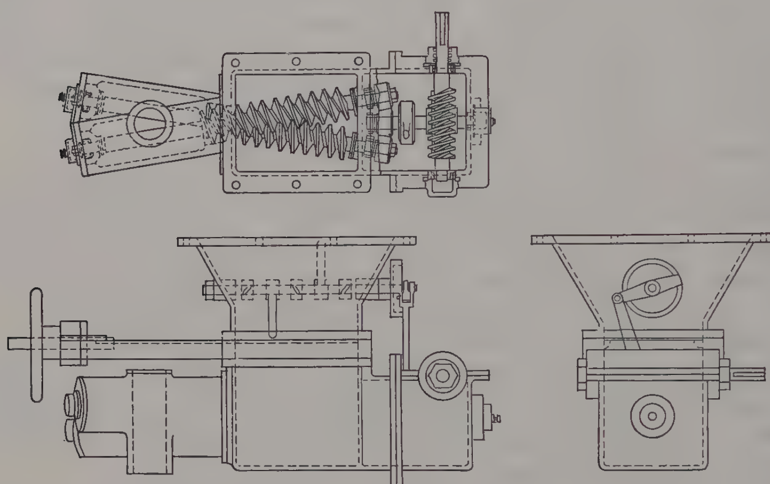


FIG. 97. Twin screw feeder for powdered coal.

turned to worms (feed screws), which have been highly developed and have found widespread application. There are many screw feeders on the market; a modern example (see Fig. 97) will explain the type. Coal is admitted from above, through a box equipped with a rocking agitator (the box is omitted in the plan view) and drops into the box containing the twin screws. From there it is fed into a compartment where it meets primary air and is transported by the primary air to the burner. The feeder is claimed to be flushproof, which means that even very dry coal will not run through on its own accord.

If the screw feeder is intended for a powdered-coal furnace with a wide range of heating capacity, the speed of the feed screw must be adjustable within wide limits. On large furnaces, two or three feeders can be provided, some of which can be stopped at light loads.

Feeders are usually located in rather inaccessible places, under bins that contain powdered coal. It is advisable to drive each feeder by

a variable speed motor and to locate the speed control at a place where the operator can observe the flame.

Siphon feeders inspirate coal dust by a jet of air flowing at high velocity. They are irregular in their action, and have not been accepted by the art.

Another method of feeding consists in equipping each furnace with an individual pulverizing mill, including a fan. Regulation of the mill controls the supply of coal dust to the burner. In this case the feeding is accomplished by air, which carries in suspension all the dust delivered by the mill. At present this method is applicable to large furnaces only, because small pulverizers have not been developed to the point where they can furnish uniformly fine coal dust at a reasonable investment, a reasonable expenditure of power, and a reasonable cost of maintenance. Another difficulty which has not been overcome with all unit pulverizers is uniformity of pulverization with regard to time. Many grinders work well when new, but after some time deliver large particles of coal.

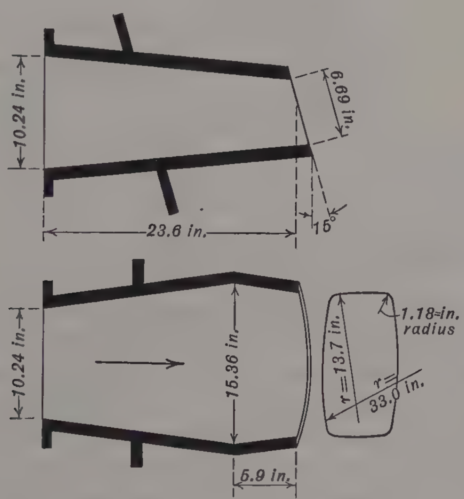


Fig. 98. Flat-flame burner for powdered coal.

Burners for Powdered Coal. Judged from an ideal standpoint, a burner for powdered coal should mix the coal dust with the minimum permissible amount of primary air (for the purpose of insuring quick ignition) and should deliver secondary air in such a manner that the air is mixed with the coal dust after the latter has been raised to ignition temperature. Attaining this object is not easy. As a matter

of fact, the ideal is often disregarded for burners that serve long furnaces of the pusher type. Such burners are nothing but spouts. They deliver coal dust that is mixed with all of the combustion air. A spout burner is illustrated in Fig. 98. Ignition is slow; however, this fact is an advantage and not a detriment for a long, continuous furnace.

No coalfired industrial (metal-heating) furnaces of any consequence having been built in America since early in 1945, infoımation on progress must be sought elsewhere. In the January 18, 1951, issue of *Stahl und Eisen,* Karl Kessels published a paper on heating furnaces that

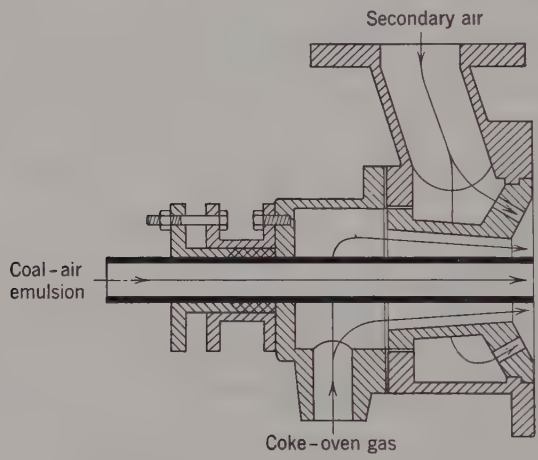


FIG. 99. Combination burner for powdered coal and coke-oven gas.

are fired by powdered coal. This paper contains detailed information on all German furnaces that are fired by powdered coal. A very interesting item in Kessels' article is a combination burner for powdered coal and clean coke-oven gas. His drawing is here reproduced as Fig. 99. Another combination burner illustrated in Kessels' paper shows the fuel gas in the central pipe, surrounded by the coal-air emulsion and by an outer ring of secondary air. The gas flame is a great help in lighting up. The burner of Fig. 99 is reconmmended for side burners, whose value (in continuous furnaces) is at last being recognized in the United States.

In comparatively short furnaces of the batch type or the continuous type the burner illustrated in Fig. 100 has given good results. Speed of combustion can be adjusted by changing the inclination of the two streams, coal-air emulsion and secondary air.

Proof that a crude burner, such as the burner shown in Fig. 98, does

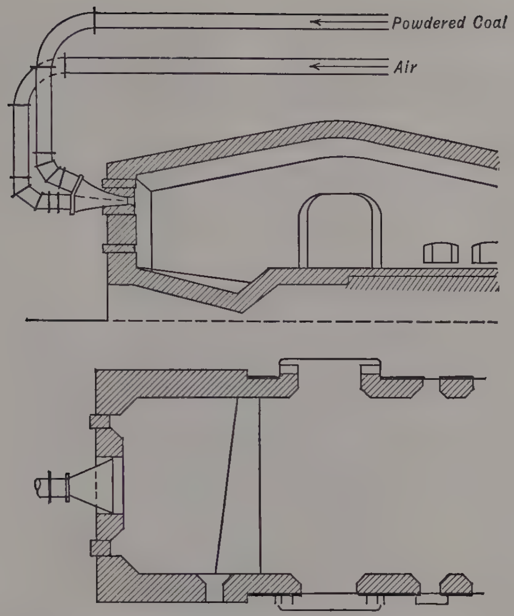


FIG. 100. Powdered-coal burner with secondary air under coal-air emulsion.

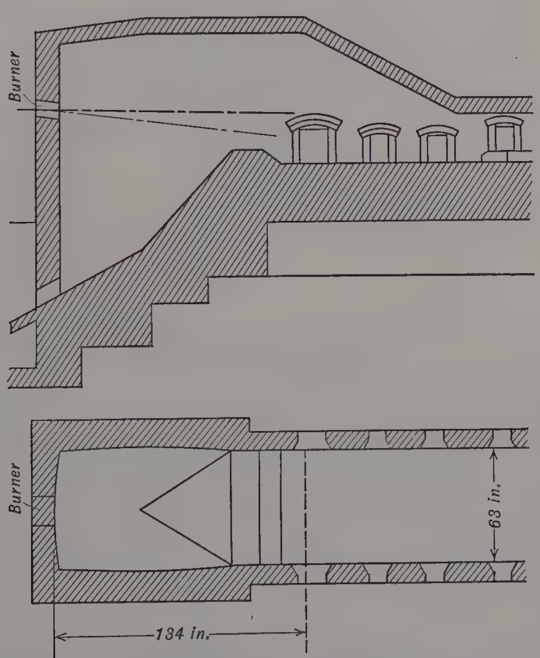


FIG. 101. Combustion chamber for burner shown in Fig. 98. Measurements were taken in the plane of the dot and dash line.

very well for a long, continuous furnace is furnished by Figs. 101, 102, and 103. They illustrate tests that were made by H. Schwiedessen and were reported in the *Archiv für Eisenhüttenwesen,* December 1931. Fig. 101 is the combustion chamber in which the tests were made. The furnace is of the side-discharge type. The incline at the

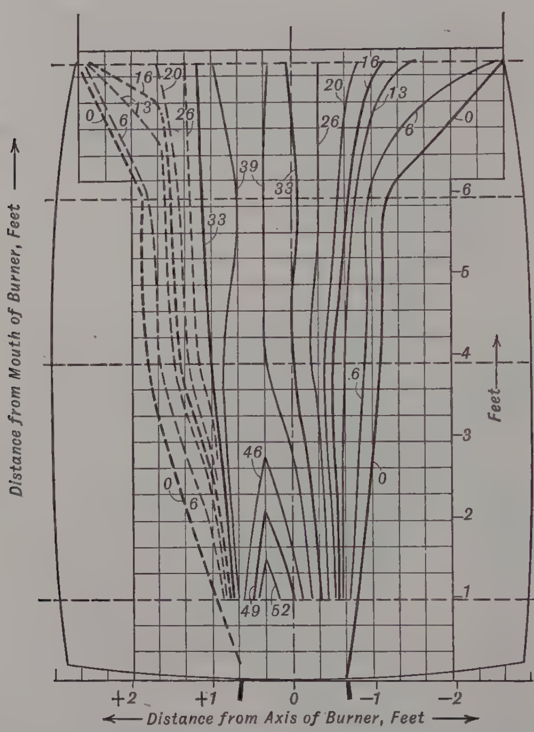


FIG. 102. Lines of equal velocity (ft/sec) of products of combustion in combustion chamber, Fig. 101.

extreme left front serves for removal of molten slag. The dimension from front wall to discharge door is given for comparison with the test data of Figs. 102 and 103. Fig. 102 shows the velocity distribution of the gases in the almost horizontal plane of the flame, measured in the hot furnace. Fig. 103 shows the percentage of solid carbon that has been burned. The highest temperature (about 2700 F) is reached after 0.22 sec. To burn 95 per cent of the solid carbon requires 0.5 sec. In the measuring process partly burned coke particles were caught; they were encased in slag.

The long combustion chamber shown in Fig. 101 is characteristic

of all continuous furnaces that are fired with powdered coal, as may be seen from Figs. 104 and 105. The optimistic hope is that heavy

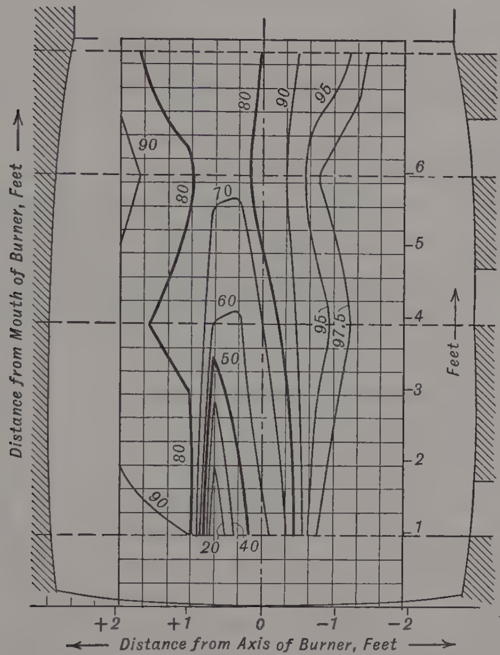


FIG. 103. Lines of equal percentage of solid carbon, burned in combustion chamber, Fig. 101.

particles will drop down before they reach the charge and that the rest will be light enough to float through the furnace without dropping on the charge.

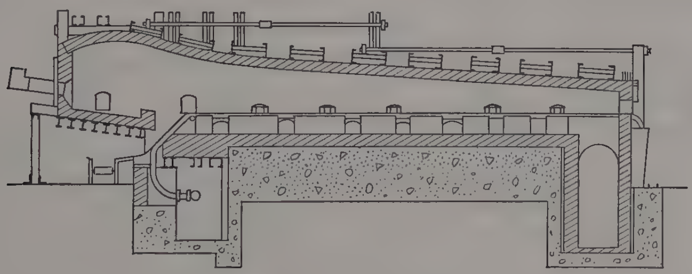


FIG. 104. Billet-heating furnace, fired by powdered coal.

The upshot is that spout burners through which coal plus all of the combustion air flow are suitable for long furnaces that are equipped

with long combustion chambers. If quick ignition is an object, from 25 to 35 per cent of the combustion air acts as coal carrier and as primary air. The remainder of the combustion air is admitted through separate openings.

The secondary air may be preheated, the primary air must be cold. If the primary air were hot, the coal would stick in the pipes.

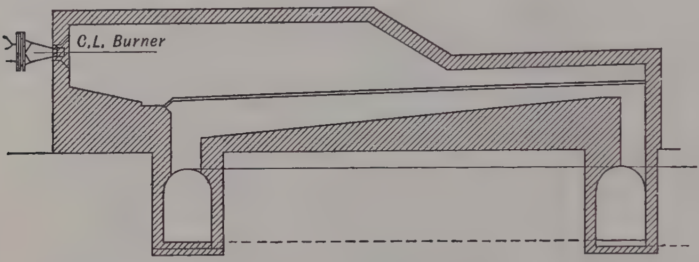


FIG. 105. Billet-heating furnace, fired by powdered coal.

Capacity of Burners for Powdered Coal. Both the upper and the lower limit of usefulness of a burner are determined by velocities. If the velocity is too great, the coal is blown too far into the furnace before it is ignited. If the velocity is too low, not only is there a danger of flashback, but coal dust is deposited in the burner and supply pipe. The latter effect is self-regulating. Coal dust is deposited until the remaining opening is small enough to make the air flow at so high a velocity that no more coal is deposited.

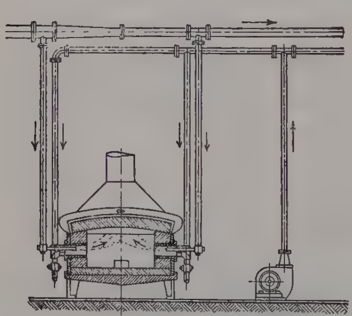


FIG. 106. Powdered-coal-fired furnace with opposite impinging jets.

Experience has shown that the velocity of the coal-air emulsion should not be smaller than 35 ft/sec at the lowest rate of firing. Under average operating conditions the velocity is, of course, higher—about 100 ft/sec. If the secondary air is cold, it may at low rates of firing be partly diverted into the coal-air emulsion duct, whereby (even at extreme turndown) the velocity is kept high enough to prevent flashback and coal deposits. This possibility does not exist in the spout burners. They must work with a maximum velocity of 150 ft/sec if a great turndown ratio is required. The high velocity explains the long combustion chamber.

Small furnaces require burners with shortest possible flame length in order to keep the flame from impinging upon the walls before combustion is complete. To a very moderate extent, the difficulty has been overcome by arranging two burners opposite each other, as shown diagrammatically in Fig. 106. In spite of this arrangement, not completely burned particles strike the opposite wall and cause trouble because it is impossible to have each carbon particle met by an opposing partner. It should also be mentioned that the flame is easily extinguished in small furnaces whenever a cold charge is placed therein.

Electric Heating Elements (Resistors)

Methods of Electric Heating. Any material through which an electric current flows is heated thereby. The rate at which heat is generated in unit time and in unit volume of the material depends upon the current density and upon the specific resistance of the material which will hereafter be called a *resistor*. The temperature which the resistor assumes depends upon the rate of heat generation and upon the rate of heat abstraction. By a judicious balance between these two actions, the resistors (or heating elements) can be used through a very wide range of temperatures.

Electric energy can be utilized for heating purposes in industrial furnaces in several ways.

1. The material to be heated serves as resistor.
2. Separate heating elements transfer heat to the stock or charge by radiation and convection; in this case:
   (*a*) The heating elements are in the heating chamber; or
   (*b*) The heating elements are separated from the heating chamber by a muffle wall.
3. The material is heated by induction currents.

Heating elements may be metallic or non-metallic. If they are metallic, they are cast, rolled, or drawn.

The Material to Be Heated Serves as Resistor. For certain purposes this method has been developed to a high state of perfection. It originated with simple machines for heating rivets and was gradually extended to the heating of bolts for heading and of longer bars for forging. The principle is the one that was used long ago by Thompson for electric welding. The part to be heated is in the low-tension circuit of a stepdown transformer. The time required to heat steel or other metal varies with its dimensions and electrical resist-

ance and with the electrical and magnetic characteristics of the heater. Uniformity of gage or cross section is closely related to uniformity of heating by this method. Rivets below ½ in. in diameter are heated in about 20 sec. Those of ¾- to 1-in. diameter require not quite a minute, while larger ones require proportionally more time. A 5-electrode rivet heater is illustrated in Fig. 107. Depending upon their length, the rivets are inserted into the proper sections of stepped chambers in the upper part of the machine. Heating occurs while the treadle is held down.

In the heating of larger bars several problems arise. The longer the bar, the greater is the voltage drop through the bar. If the bar has a large cross section, the electrical contacts cause difficulties. The cross section of the bar grows as the square of the diameter, whereas the circumference is proportional to the diameter. In order to furnish the necessary contact area, the contacts must be made long, and then temperature uniformity suffers. Condition of the contact surfaces is often unknown; thickness of mill scale is an example. As a consequence of these factors direct resistance heating has been limited to bars of 2½ in. square and to a temperature of 2200 F. The center of the bar is about 50 F hotter than the outside, because it takes about five minutes to heat a 2½ in. bar; during that time, heat is radiated to the surroundings. It follows that the kilowatt-hours per ton are smallest for the bars of the smallest diameter. To heat a 1½ in. square bar to 2200 F requires 16½ kw-hr per 100 lb; heating a 2½ in. bar requires 40 per cent more electrical energy per 100 lb.

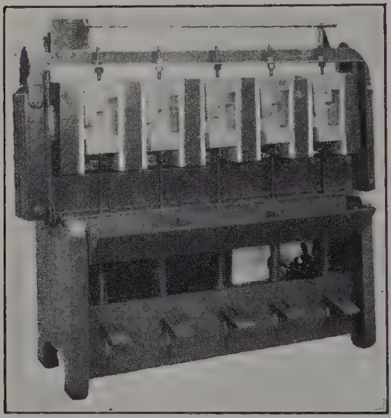


Fig. 107. Electric rivet heater.

In spite of the high cost of electrical energy, direct-resistance heating is used, because of the short heating time and the convenience of the process. When a bar of large diameter and great length is to be heated, the demand for energy is so great that it would not be advisable to take all of it out of one phase. Additional contacts are then provided along the bar with the intention of balancing the three phases.

Fig. 108 illustrates a machine for direct-resistance heating. The bar that is being heated lies in the open (it is not surrounded by a furnace), and a steel bar of 1-inch diameter is heated in less than a

minute. Putting a hinged furnace around the bar would not produce any saving, because the bar must be so located that it can be kicked out and replaced by a cold bar without any delay. With large bars the heating time is long compared to manipulation time. A hinged enclosure would, in that case, save heat and promote uniformity of temperature.

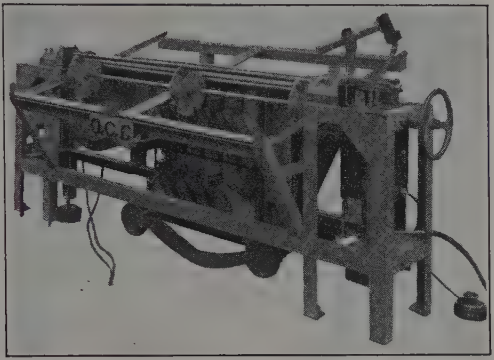


FIG. 108. Electric heater for bars 6 ft long. The machine is controlled by an electric eye.

Direct-resistance heating cannot be used, if the cross section of the bar to be heated varies. The portions having a large cross section stay colder than the thinner sections. In such cases, direct-resistance heating has been augmented by induction heating of the thicker portions. In the heating of rivets lack of temperature uniformity is welcome; the head should be colder than the stem.

Direct-resistance heating is at its best in mass production, in which identical pieces are heated for months or even years.

Non-Metallic Resistors. At the time of this writing, silicon carbide is the only non-metallic material that is commercially used in the United States for resistors. It withstands higher temperatures than commercial metallic resistors. In America, resistors of silicon carbide are known by the trade name Globars. These resistors have been standardized with regard to diameter and length, ranging from $\frac{5}{16}$-in. diameter $\times$ 4-in. length to $1\frac{3}{4}$-in. diameter $\times$ 66-in. length. For each size, the properties of the element and the recommended thickness of furnace wall are found in tables that are published by the manufacturers.

Resistors of silicon carbide have some characteristic properties that should be known, before their installation is considered. When these resistors are heated to a temperature above red heat, the carbon in

the silicon carbide very gradually burns to carbon dioxide (in exceptional cases to carbon monoxide), while the silicon burns to silica. These reactions are very slow; they are accelerated if the temperature grows to bright white heat. Several conclusions can be drawn from this fact. One of them is that silicon carbide resistors should not be installed too close to a furnace wall, at least not in high-temperature furnaces. Those parts of the resistor which are closest to the wall cannot get rid of the heat; they are hottest and are oxidized most rapidly. Experience has taught that the distance from center of element (resistor) to wall should be not less than two element diameters, unless space is at a premium. This relation is shown in Fig. 109, which illustrates a vertical heating element. Fig. 110 shows a horizontal element. Another conclusion is that the elements must not be too close to each other. The minimum spacing from center to center of elements equals two diameters. A closer spacing interferes with reradiation from the furnace wall and causes overheating of the wall side of the elements. If the charge is stationary, as in a batch-type furnace, the maximum permissible spacing from center to center of elements equals 1.4 times the distance from the center line of the element to the surface to be heated.

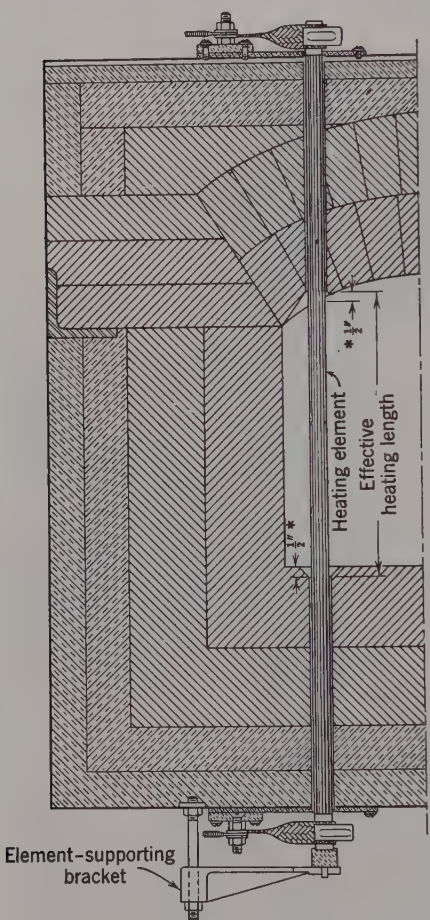


FIG. 109. Silicon-carbide heater, mounted vertically. Courtesy of Carborundum Co.

Another effect of oxidation is that the resistance of the heating elements increases with time. The heat emission of an element is kept practically constant by the use of one of several means, namely: (1) multiple-tap transformer, (2) induction regulator, (3) saturable

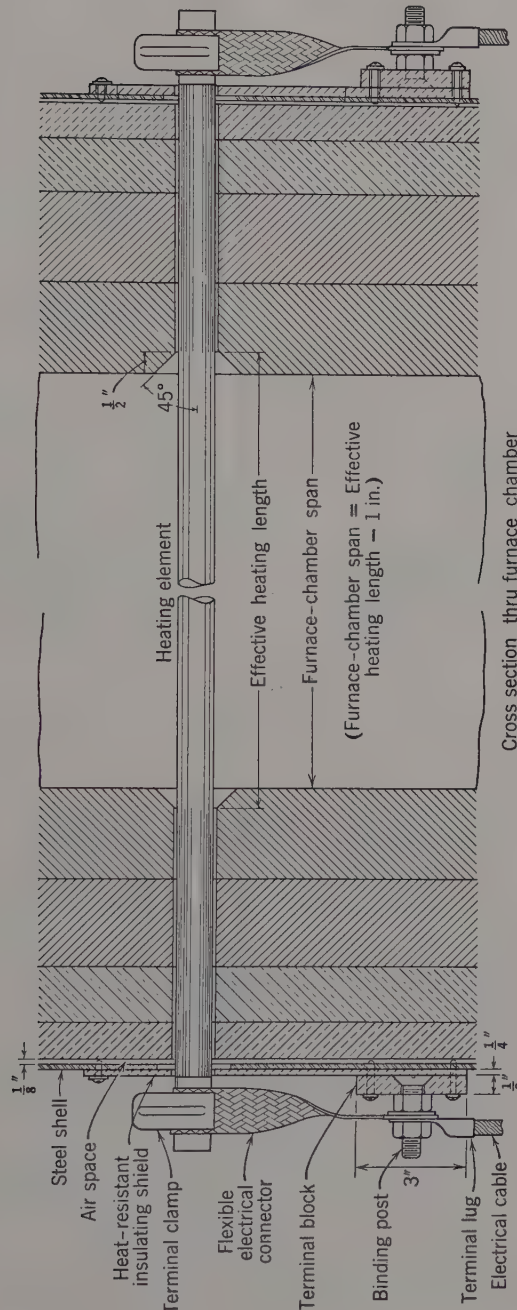


FIG. 110. Silicon-carbide heater, mounted horizontally. Courtesy of Carborundum Co.

reactor, and (4) external rheostat. The multiple-tap transformer has the widest use.

The resistivity of silicon carbide, in British-American units is expressed as follows: A bar of 1-in. diameter and 12-in. heating length has a resistance of 0.62 ohms at 1960 F.

The length of useful life of a silicon carbide resistor depends upon many factors, which will now be discussed. They are furnace temperature, frequency of shutdowns, and location of elements in furnace.

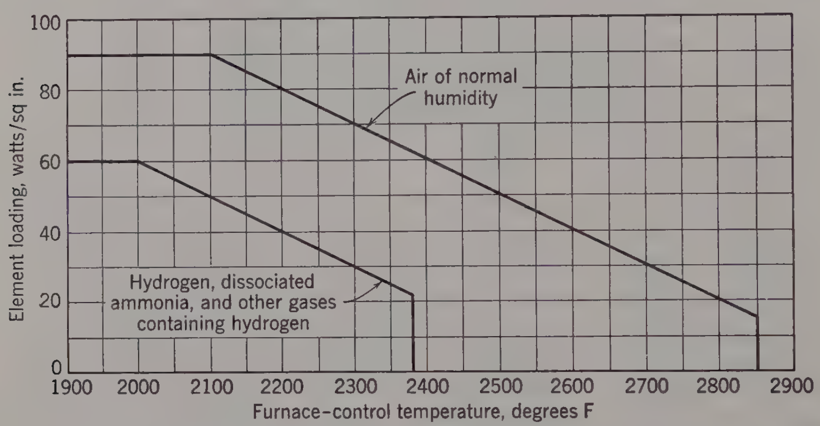


FIG. 111. Recommended surface loading of Globar resistors as a function of temperature.

These factors vary the life of an element from 2000 hours to 10,000 hours, for temperatures as high as 2300 F. Element loading, in watts per square inch, also affects element life. Recommended surface loading as a function of furnace temperature is given in Fig. 111. The reason for recommending a lower surface loading in furnace atmospheres that contain hydrogen is not clear. The hydrogen destroys any protective layer of silica, but it also protects silicon and carbon against oxidation. The effect of frequent shutdowns is bound up with the expansion characteristics of silica. The oxide, formed on the surface of silicon carbide, undergoes violent changes of volume near 1000 F. These changes of volume open up the pores in the elements and pave the way for penetration of oxygen into the elements.

Globar elements are rigid at highest furnace temperatures. They serve equally well in horizontal and in vertical positions.

Those parts of the elements which are located in the walls, roof, or hearth must either have an enlarged cross section or be made of a material with high conductivity. The latter method is now preferred.

The in-the-wall portions of the elements are made of silicon carbide with an excess of free silicon. The conductivity of this material is sufficiently high to prevent an accumulation of high temperature in any of the walls.

Two practical rules may be welcome. Globar elements are replaced when their resistance has been doubled. Silicon carbide is a ceramic material, and is sensitive to shock. Furnaces that are heated by Globar elements should rest on springs (as shown in Volume I), if located close to steam or drop hammers.

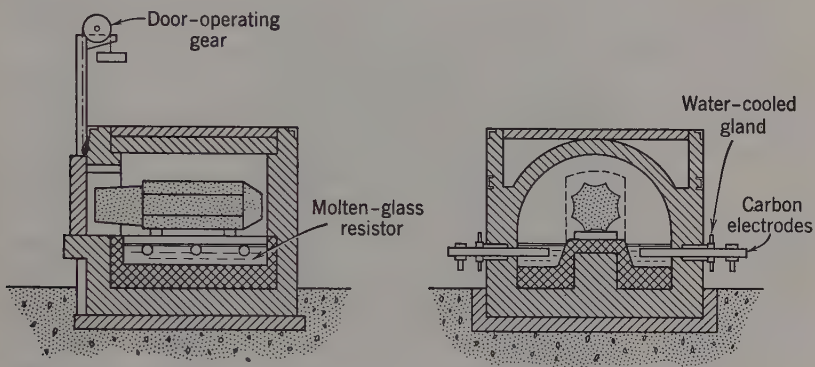


Fig. 112. Furnace in which glass serves as electric resistor.

Glass Resistors. Molten glass as a resistor for electrically heated industrial furnaces was developed in Italy.[6] In regions with cheap electric power and with dear fuel, the use of glass resistors is attractive, even for the heating of ingots. Fig. 112 illustrates how the glass is applied for ingot heating. On each side of, and lower than, the ingot, three carbon electrodes (for three-phase current) are inserted into the glass. Cold glass is an insulator. For starting the flow of electricity a ditch of molten glass must be established across the electrodes. A gas flame or an oil flame serves that purpose. Evidently care is needed in placing the ingot and in removing it.

At 2400 F, each square foot of the glass bath dissipates approximately 15 kw. In continuous operation, a net ton is heated to 2300 F by 310 to 320 kw-hr. With the usual shutdowns, the power consumption rises to 360 kw-hr. The arrangement of the glass bath with relation to the charge depends upon the type of furnace (batch or continuous) and upon the shape of the pieces to be heated. The article cited in the footnote contains detailed information on the use

[6] The use of glass resistors was described in *Iron Age,* June 15, 1950, pages 95–98.

of glass for resistors. The auxiliary electrical equipment is the most expensive part of the installation.

Metallic Resistors. Resistors made of metal can be classified according to:

1. Their composition.
2. Method of production (cast, rolled, or drawn).
3. Method of protection (bare or sheathed).

Composition. Unalloyed iron or soft steel may serve as a resistor in oxidizing atmospheres below 800 F. In protective atmospheres or in vacuum it withstands higher temperatures. In such atmospheres the creep strength limits the highest safe temperature.

For temperatures between 1000 and 1500 F, iron alloyed with nickel and chromium is serviceable in oxidizing atmospheres. The higher the temperature, the lower the iron content must be, except in neutral or deoxidizing atmospheres. In deoxidizing atmospheres an alloy of 35 per cent nickel, 20 per cent chromium, and 45 per cent iron is durable for resistor temperatures up to 1950 F. If so high a temperature is encountered in air or other oxidizing atmospheres, the most commonly used resistor material contains no iron but consists solely of 80 per cent nickel and 20 per cent chromium. This iron-free alloy is, in the United States, most widely known as Nichrome, which is a trade name of the Driver-Harris Company and is registered in the U. S. Patent Office. Anybody can make, sell, or use this alloy, but only the owners of the trade name may use the word Nichrome.

The resistance to oxidation of the 80 and 20 alloy is greatly increased by the addition of very small amounts of some other metals, such as Be, Ca, Si, Ti, Zr, Ce, and still others. In 1954 these additions had not yet been standardized. Further information may be obtained from *Metal Progress*, December 1949, page 866, or from the original publication in the *Zeitschrift für Metallkunde,* February 1949, page 73.

In some protective atmospheres and within the temperature range between 1650 and 1850 F, the 80 and 20 alloy is subject to the formation of "green rot," which destroys the elements in a few months. Under the same conditions an alloy of 35 per cent Ni, 18 per cent Cr, and at least 1.25 per cent Si (the rest being Fe) has given good service. For temperatures above 1900 F, the standard 80 and 20 alloy is durable.

Still higher temperatures are safely withstood in oxidizing atmospheres by an alloy of Swedish origin (trade name *Kanthal*). It con-

sists of $3\frac{1}{2}$ to 6 per cent aluminum, 19 to 25 per cent chromium, 0.5 to 3 per cent cobalt, the rest being mainly iron. The alloy with the highest content of aluminum, chromium, and cobalt is safe with element temperatures up to 2460 F, in air or in other oxidizing atmospheres. Unfortunately, the Al-Cr-Co-Fe alloy is attacked by many protective atmospheres, which destroy the tight protective skin of

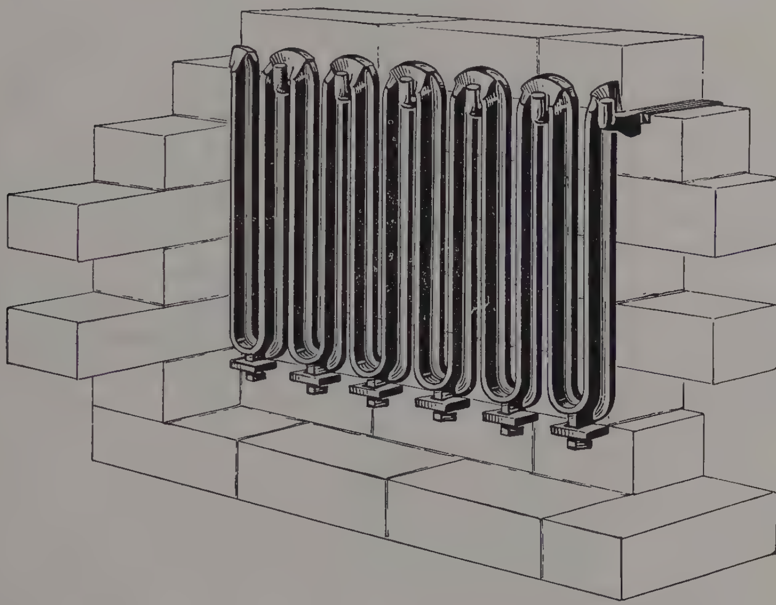


FIG. 113. Cast grid resistor mounted on sidewall.

aluminum oxide. The alloy is ductile; when new, it can be bent and twisted. In service it becomes brittle and loses creep strength. The rather general adoption of protective atmospheres has greatly reduced the field of application of Kanthal.

Classification According to Method of Production. Metallic resistors are either cast, rolled, or drawn. A cast resistor is illustrated by Figs. 113 and 114. Cast resistors must have a large cross section so that pipes and blowholes will not cause great variations in cross section. The great thickness offers the advantage that local oxidation does not produce relatively great changes in thickness. Local overheating is thus prevented. However, the great thickness does not permit line voltage to be impressed on the cast resistors. A transformer is necessary. About 25 years ago cast resistors were popular, partly because makers of wire and of ribbon had not yet

perfected their product and partly because the suspension methods of ribbons and wires caused trouble in the early days.

Wire is drawn. Ribbon can be rolled to any width. For low cost it is rolled as a wide strip and is then slit to the desired width. The question "Wire or ribbon?" has apparently been decided in favor of the ribbon. Wires are, of course, used in coils. The arrangement of ribbon resistors on a wall becomes clear from Fig. 115, in which two banks of ribbons are shown. Twin banks are installed in large furnaces, because the maximum length of a hanging loop is determined by the creep strength of the resistor material. Strangely enough, the Al-Cr-Co-Fe element, which can withstand higher temperatures than the 80 and 20 Ni-Cr element can withstand, has a low creep strength. And since this alloy is installed mainly for temperatures of 2200 F or higher, the ribbons cannot be suspended but must be waved and supported by refractory shelves. The method is illustrated by Fig. 116. When resting on ceramic shelves the elements cannot radiate

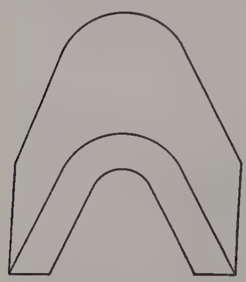


FIG. 114. Detail of cast resistor shown in Fig. 113.

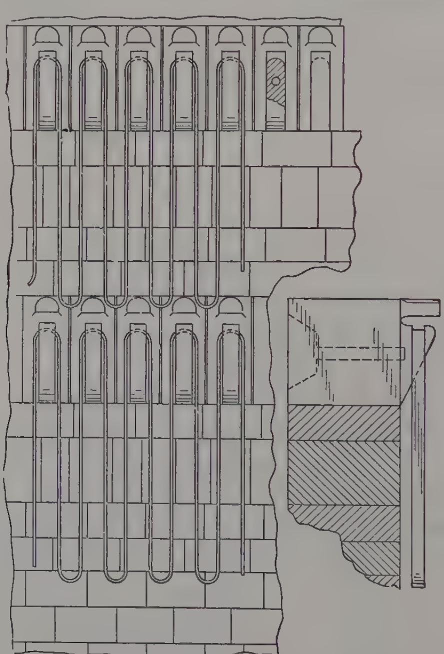


FIG. 115. Ribbon-resistor mounting, with supporting plugs and projecting knobs.

freely. It follows that in some places the radiation is limited so much that element temperature will be greatly in excess of furnace temperature. In spite of this fact, the elements are good for at least 2300 F furnace temperature. Since the Al-Cr-Co-Fe element can be

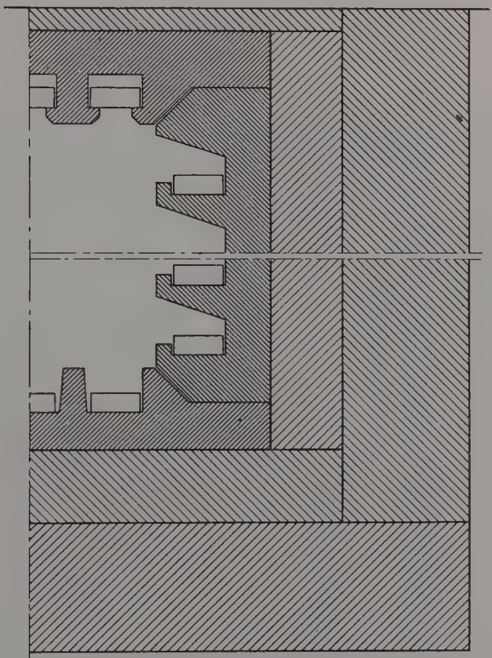


FIG. 116. Method of supporting temperature-resisting alloy. Courtesy of Kanthal Co.

used in oxidizing atmospheres only, it competes, at least in metal-heating furnaces, directly with open-flame heating. This fact makes the element especially useful for localities in which electrical energy is cheap and fuel is dear. It competes with glass as a resistor.

The makers of the Al-Cr-Co-Fe element recommend the following values of heat dissipation:

Furnace Temperature, F	Kw per Sq Ft of Wall
2000	1.9 to 2.8
2100	1.8 to 2.7
2200	1.7 to 2.5
2300	1.5 to 2.5
2400	1.2 to 1.7

The low values are recommended for average conditions. The high

values apply when quick heating is required at the expense of life of elements.

Sheathed Resistors. Metals that withstand temperatures above 2300 F in different furnace atmospheres are too expensive for practical use, if such metals exist at all. Platinum, for instance, is embrittled in an atmosphere that contains carbon monoxide. Molybdenum remains rigid at very high temperatures but is quickly oxidized above dull red heat. The oxide is vaporized and exposes clean metal to continued oxidation. In laboratory furnaces, molybdenum was used in a protective atmosphere. For many years molybdenum was encased in beryllium oxide that was surrounded by sillimanite. The latest development of the molybdenum resistor was described and illustrated in *Powder Metallurgy Bulletin,* Volume 6, Number 1 (April 1951). The illustration is here reproduced as Fig. 117. The gas-tight ceramic tube, 1, contains a helical coil, 2, of molybdenum wire. The return lead lies in the axis and is insulated from the coil by ceramic beads, 3. The two ends of the wire are connected to metal terminals, 4 and 5. Item 6 is a glass seal. Item 7 is a glass ring. The electrical connections are made to the threaded portions, 8 and 9. This vertical heating element stands or falls with the possibility or impossibility of securing a thin, gas-tight ceramic tube. The life of the element is 8000 hours at a temperature of 2400 F. At 2700 F the life drops down to 800 hours.

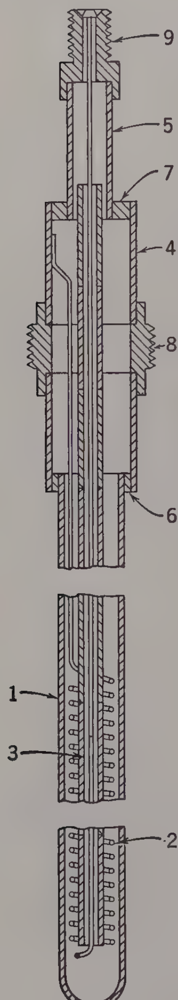


Fig. 117. Molybdenum resistor in gas-tight enclosure.

Mounting of Metallic Resistors. The mounting of sheathed resistors and of the Al-Cr-Co-Fe elements for high-temperature service was described above. For temperatures below 1800 F, both the nickel-chromium alloys and the Al-Cr-Co-Fe alloys can be mounted in the form of loops or coils. A wall mounting of looped ribbon is illustrated in Fig. 115. Coils of wire have all but disappeared, because radiation from some parts of the coil is obstructed. The obstruction reduces the safe surface loading in watts per square inch and increases the cost of the installation. In Fig. 115 the ribbons are supported from ceramic

knobs. While ceramic supports are seemingly inexpensive, they are actually dear, because they do not dissipate the heat that is generated in the ribbons where they contact the ceramic knobs. The safe surface loading of the ribbon is thereby reduced. In modern installations the supports are made of heat-resistant metal, which dissipates the heat energy that is generated in the contact area. Metal sup-

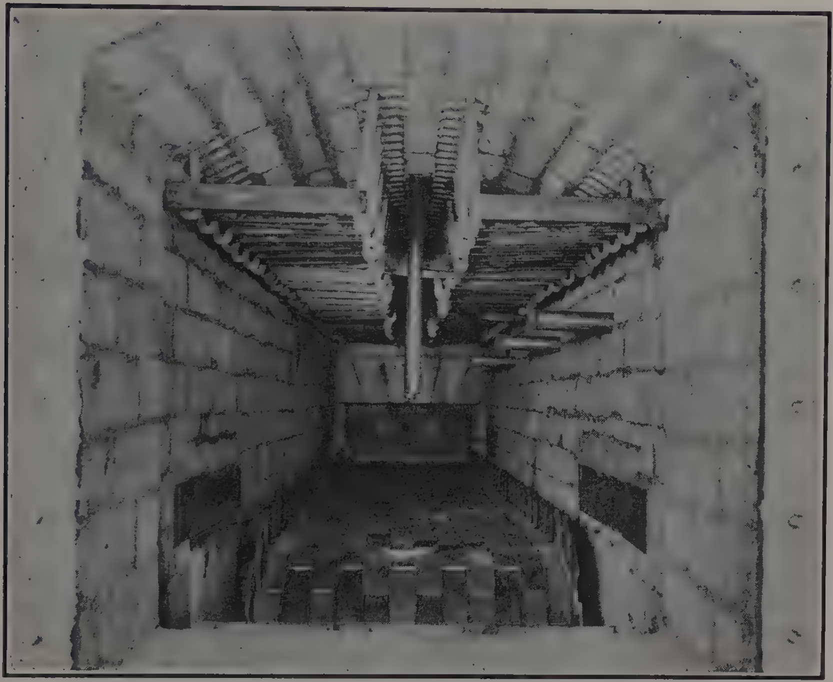


Fig. 118. Suspension of resistors from roof. Courtesy of Westinghouse Electric Co.

ports are likewise used for supporting ribbons that are located under the roof. This arrangement is clearly shown in Fig. 118. The tube in the center is a pyrometer. The upper ends of the hooks are inserted in slots and are then turned.

The under-the-roof support illustrated by Fig. 119 is now installed rather seldom. In this arrangement, frames with heater ribbons are slipped into the furnace immediately below the roof, as soon as a ribbon has been burned through. Several reasons exist for the gradual disappearing of the design of Fig. 119. Ribbons are now of uniform composition and of uniform thickness. The supports dissipate the

heat, and last but not least, engineers have learned how to figure the ribbon temperature correctly.

Heat is applied to the charge from below by several methods. If the charge is such that no scale or small metallic particles drop down from it, bare ribbons are mounted under the hearth in the manner shown in Fig. 120. Ceramic spacers keep the ribbons in the proper

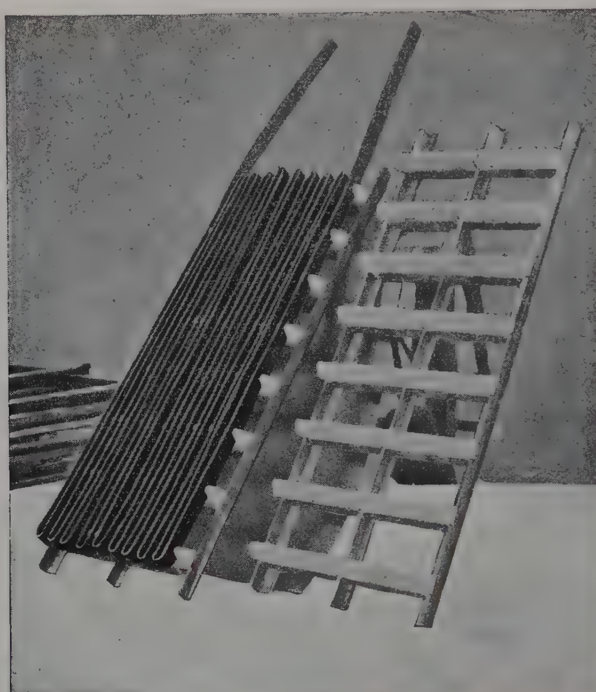


Fig. 119. Ribbon resistor with corrugated refractory supports and alloy frame.

position; metallic spacers would cause difficulties. In furnaces of the batch type the ribbons are covered over by an alloy plate with appropriate space between plate and ribbons. Resistors are not arranged under moving hearths. Instead, the sidewalls are extended downward and are covered with ribbons.

Capacity of Metallic Resistors. The capacity of the Al-Cr-Co-Fe elements was given on page 133. The length of life of a properly mounted metallic element depends upon its temperature, its material, and the composition of the surrounding gases. The range of possibilities in each of the three variables is so great that a standardization is out of the question. Each builder of electrically heated furnaces

has, by laboratory and field experience, arrived at his own standards, which do not necessarily agree with the experience of others. It is evident that so-called protective atmospheres also protect heating elements and that a less expensive ribbon material can be installed in such atmospheres. For all elements the following is true: A small increase in ribbon temperature vastly increases the heat dissipation.

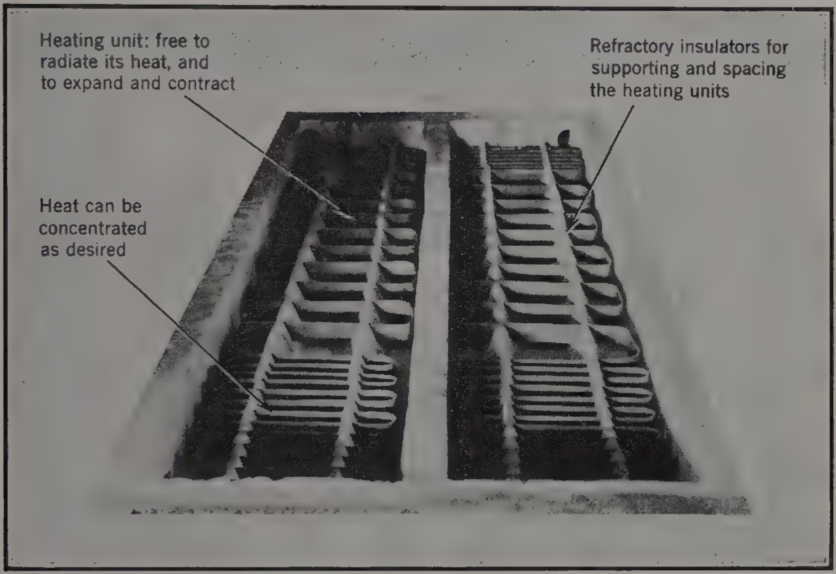


Fig. 120. Method of mounting resistors under the furnace hearth. Courtesy of General Electric Co.

For a given heating capacity, for instance in pounds per hour, the hotter ribbon results in a smaller and less expensive furnace. But the life of the ribbon is reduced. The old problem is encountered: Low first cost or low maintenance?

A rating that is applicable to resistors of all types and materials is the surface loading, which is usually expressed in watts per square inch of element surface. To make this unit practical a standard spacing in multiples of wire diameter or of ribbon width must be adopted. If the spacing differs from the standard, the surface loading is changed accordingly. As an example, the surface loading of 80-20 Ni-Cr elements will be discussed. Fig. 121 conveys a clear idea of the relations. In that illustration the ordinates indicate the surface loading of the elements; the abscissae represent furnace temperatures, which are always a little higher than the final temperature

of the charge. The ΔT curves are meaningless except at the points where they intersect the A curve. They indicate by how much element temperature may exceed furnace temperature. Curve A is to be used for a low-cost furnace that contains an oxidizing atmosphere. For long life of the elements in an oxidizing atmosphere, about 80 per cent of the surface loading indicated by curve A is recommended. If the elements are glowing in a truly inert atmosphere, values 50 per cent higher than those indicated by curve A are perfectly safe with regard to burning out. In non-oxidizing atmospheres, creep strength is the deciding factor.

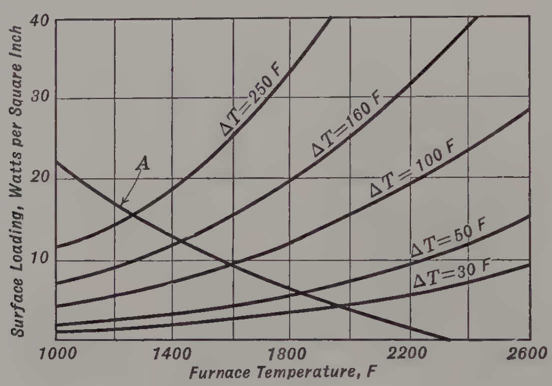


FIG. 121. Surface loading and excess temperatures of nickel-chromium resistors.

The surface loading taken from Fig. 121 holds for elements which can dissipate the heat freely. Actually they radiate to one another more or less, depending upon the closeness of the spacing. In consequence, the values obtained from Fig. 121 must be multiplied by a fraction which can be taken from Fig. 122. It is immediately evident that it does not pay to crowd the elements. The furnace becomes smaller, but the cost of the resistors and fasteners goes up.

With the surface loading decided upon, the next step is to calculate the cross-sectional dimensions of the elements. The heat to be liberated by them in unit time is known (see calculations in Volume I). The line voltage is known. If line voltage is too high for any suitable arrangement of elements, or if it calls for resistors that are impracticably thin, then a stepdown transformer becomes necessary.

Calculation of the resistors (cross section and length) may proceed along different paths. As a rule, the kilowatts are known, as indicated in the preceding paragraph. If the voltage is known, if the surface loading is assumed, and if the electrical conductivity of the

element material is known, the cross section of the element can be computed, and with this cross section the length can be calculated.

In practice, a different method is followed. The calculation is greatly simplified by making the spacing of the ribbons equal to their width. In that case, a definite, invariable relation exists between surface loading and kw/sq ft of wall. This relation follows from the equation: Watts per sq in. $\times$ 2 width $\times$ 144/width = 1000 kw/sq ft of wall, and kw/sq ft = 0.288 watts/sq in. Thus, 20 watts per square inch of ribbon surface equal 5.76 kw/sq ft of ribbon-covered wall. It might be mentioned that not all builders of resistor furnaces make

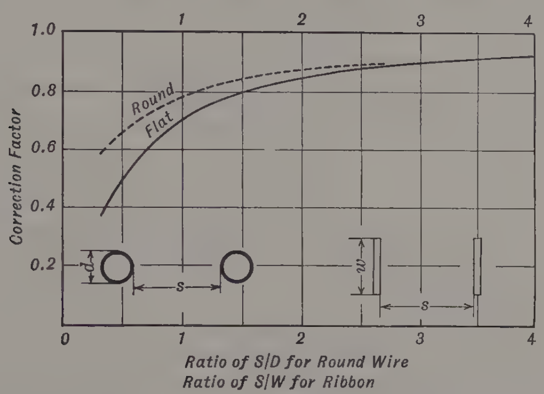


FIG. 122. Correction factor as a function of spacing of elements.

the spacing equal to the width of the ribbon. One prominent builder works with a uniform spacing of 1½ in. for ribbon widths of ¾ in., 1 in., and 1½ in.

Width, thickness, and length of ribbon are to be so selected that, if possible, the required kilowatts can be obtained with line voltage. The calculation roughly proceeds as follows:

1. On the basis of furnace temperature, furnace atmosphere, material of element, and life of element, select the surface loading in watts/sq in. This is probably the most important step. Convert the surface loading into kw/sq ft of wall surface.

2. Experience has taught that the wall area which is available for placing elements is 0.75 of the total area. This fraction allows for thermocouples, supports, corners, etc.

3. From (1) and (2) find total kw input. If more heat release is needed, more wall space must be provided.

4. Find total resistance from ohms = volts^2/(1000 kw). Volts here means line voltage.

5. From a previously drawn chart, pick out a ribbon size that has the correct resistance. In order to construct the chart, the engineer must know the resistance per foot of different-sized ribbons at furnace temperature. This information is easily obtained from the makers of resistor ribbons. An example of such a chart is given in Fig. 123. The diagram gives the relation between ribbon-covered wall surface,

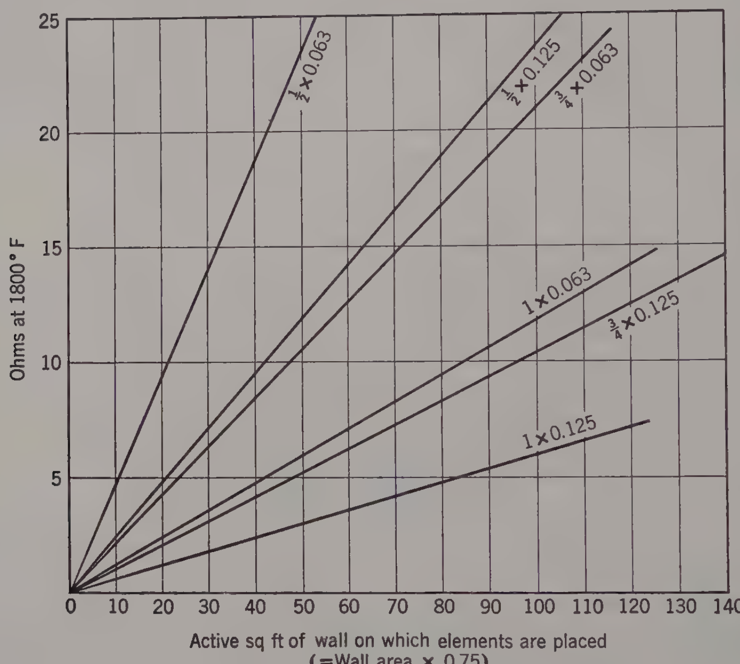


FIG. 123. Chart for finding size of ribbon resistors.

ohms (from 4), and size of ribbon. As a rule, it is possible to work in a ribbon that is kept in stock, for instance by varying the covered wall surface or the spacing or the surface loading. If not, an odd size of ribbon must be used. By "odd" is meant a ribbon that is not part of the regular inventory. Ribbons are made in many steps of width and thickness. In furnace work, a ribbon thickness of less than $\frac{1}{16}$ in. is avoided.

The makers of alloy ribbons also furnish data on creep strength and on the cost of ribbons as a function of material, width, and thickness.

The Electric Heating of Lead Baths and of Salt Baths. The conductivity of lead is so high that internal heating by electrodes is out

of the question. If lead baths are to be heated electrically, the lead pot must be surrounded by resistors that are supported by the wall of the furnace. The arrangement and calculation of these resistors do not differ from those of resistors that are used in other furnaces, except that no resistors are placed near the bottom of the pot, because lead pots burn out in time, usually near the bottom.

Pieces that are forced into molten lead are small and are heated almost instantly. The heat requirement of a lead pot, then, is the sum of heat required to heat each piece, times number of pieces per hour, plus heat imparted to submerging tools and containers, plus radiation from the surface of the bath, plus wall losses. Fortunately, the temperature of lead baths is comparatively low, usually between 350 F and 1300 F. Of course, the temperature of the resistors is higher because of the radiation jump from resistor to outside of pot and the temperature drop through the wall of the pot, the pot being a muffle.

Lead baths may be heated by induction, but this method of heating offers no advantage.

The Electric Heating of Salt Baths. Salt baths can be heated either externally or internally. Although salt baths have been heated externally by products of combustion for salt temperatures up to 1600 F, external heating by resistors is usually limited to a bath temperature of 1000 or 1050 F; this temperature is at the bottom of furnace temperatures. Calculation of resistors is identical with that for lead pots.

The great majority of electrically heated salt baths are now internally heated by immersed electrodes. This method of heating is made possible by the fact that the electrical conductivity of the salt is low when compared to the conductivity of the metal in the electrodes. With internal heating, the container may be a ceramic material that has a life up to eight years. With internal heating, salt temperatures up to 2400 F have become possible.

The electrodes may be spaced widely apart at both ends of the bath, or they may be located closely together. Wide spacing requires a higher voltage than is needed with close spacing. Widely spaced electrodes entering the bath from the top are seldom seen. Salt baths with totally submerged electrodes that enter from the sides were popular in the forties, but are scarce now. Fig. 124 illustrates a salt bath of that type; Fig. 125 shows the commonly used arrangement with closely spaced electrodes. This arrangement, when supplied with alternating current,[7] creates strong electrodynamic forces

[7] A salt bath cannot be heated by direct current on account of electrolysis of the salt.

which produce a circulation sufficient to move the molten salt away from the electrodes. A doubly beneficial result is thereby obtained. The circulation in the bath promotes uniformity of temperature and

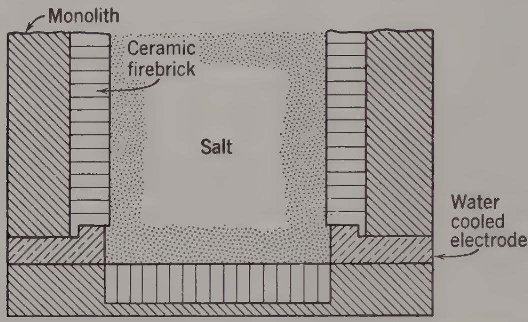


FIG. 124. Salt-bath furnace with electrodes in opposite walls.

prevents overheating of the salt near the electrodes. The circulation that results from adjacent electrodes is diagrammatically illustrated by Fig. 126. The material of the metallic electrodes is adapted to the composition and the temperature of the salt.

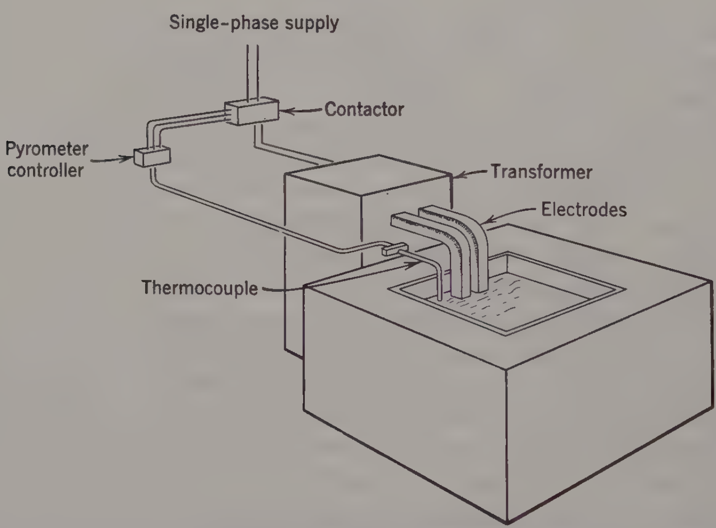


FIG. 125. Salt bath with suspended electrodes entering from the top. Courtesy of Ajax Electric Co.

In the calculation of the heat (and electrical energy) requirement of a salt furnace, radiation from the surface is an uncertain item,

because the time during which the bath radiates to the surroundings is not known. Open radiation dissipates a great deal of heat, as can be judged from a study of Fig. 127, which is based on data furnished by the A. F. Holden Company. Other makers of salt-bath furnaces figure with black-body radiation; see handbooks or Volume I. Radiation losses from the surface often exceed all other losses combined. For that reason, all possible means are provided to keep these losses down. In carburizing baths, the loss is reduced by a cover of crushed carbon. Other baths are equipped with hinged covers or with rolling

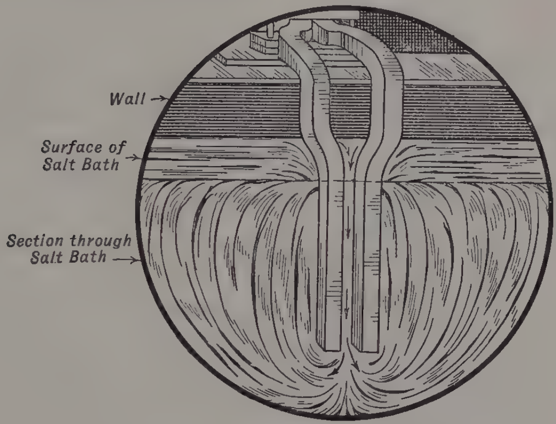


Fig. 126. Circulation in internally heated salt bath.

covers. Fig. 128 illustrates the latter type. Covering the bath while a charge is suspended in it sometimes strains the ingenuity of the operators. Evidently a liberal allowance must be made for radiation from the surface of the bath. Like all other electrically heated furnaces, salt-bath furnaces lose heat through the electrodes, the outer ends of which are frequently water-cooled. After all heat requirements have been determined, a reserve factor is allowed for occasional extra-heavy charges, melting fresh salt additions, melting the salt bath initially, and still other contingencies.

At least five factors enter into the dimensioning and spacing of the electrodes for delivering the required electrical energy: (1) the conductivity of the salt bath, which varies somewhat with the composition of the salt and varies greatly with its temperature; (2) the distance between the electrodes, this distance being usually adjustable; (3) the cross-sectional area of the electrodes; (4) the depth of immersion of the electrodes; and (5) the voltage impressed upon the electrodes. In view of the great number of variables, the most suit-

able conditions have been determined by experiment rather than by theory.[8]

The following remarks are in order: Electrodes are always arranged in pairs. If more than one set of electrodes is used, the pairs are sufficiently far apart not to interfere with the electrodynamic (circulation) effect of each pair. If one pair takes too much energy out of one phase, several (preferably three) pairs of electrodes are provided. The gap between the electrodes of a pair varies from 1 to 3 in. A smaller distance would cause overheating; a larger distance would interfere with circulation. The voltage between the electrodes must be low. It ranges between 5 and 20 volts; the current flowing in the electrodes ranges from 1000 to 8000 amperes. In practice, the power flowing in one pair of electrodes ranges from 5 to 80 kw. The cross section of the electrodes is made square or rectangular, because flat, opposing surfaces afford better concentration of the magnetic flux than is offered by curved surfaces.

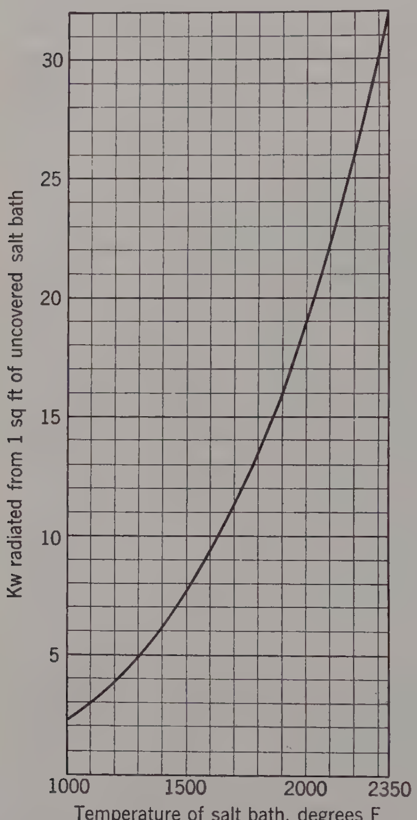


FIG. 127. Radiation loss from salt baths.

In practice it has been found that the distance between the lower end of the electrode and the bottom of the pot should not be less than 4 in. nor greater than 18 in. The immersed depth of the electrodes should not be less than 10 inches to insure an effective directional circulation; the greatest immersed depth of a single electrode is about 5 ft. For greater depth of bath, two or three sets of electrodes are arranged in vertical alignment.

Cold salt is not a conductor of electricity. For that reason, containers of cold salt, whether frozen or granular, must be started by

[8] An attempt at solving the problems by calculation was made by V. Paschkis, "Industrial Electric Furnaces," Vol. II, Interscience Publishers.

external means. A helical coil of electrically heated wire is frequently used. As a rule, salt baths are not allowed to freeze overnight or over the week end. A transformer tap for lower voltage is selected so that the power input is reduced to about one third of the working power; this keeps the salt from freezing. The overnight power input is not entirely lost, because it permits quicker starting and thereby saves wages.

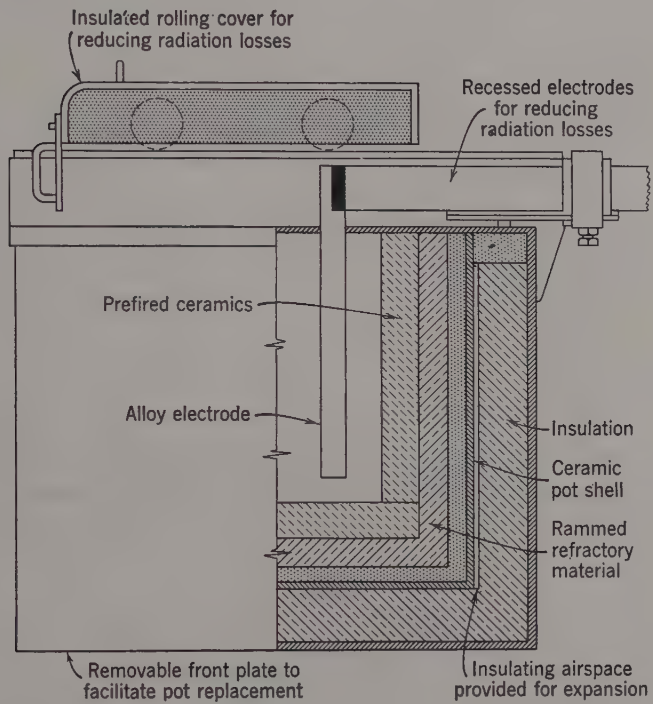


FIG. 128. Movable cover for salt bath. Courtesy of A. F. Holden Co.

Salt baths may be heated internally by radiant tubes. Fig. 129 illustrates this method. Care must be taken in heating this furnace after a freeze, because most of the heat is imparted at the bottom, which might expand while the top is still solid. The temperature to which salt can be heated by a radiant tube is limited to approximately 1600 F.

Equipment for Induction Heating. The principal equipment in induction heating is a coil in the wire of which an alternating current flows. The alternating current induces eddy currents in any metal that either is located within the coil or closely surrounds the coil.

The frequency ranges between 60 cps and 15,000 cps. Still higher frequencies are employed in special applications.

Heat is generated in a metallic charge by induction regardless of the composition of the non-metallic material in the gap between charge and coil. In the heating of small bars, up to about 2½-in. diameter, air gaps are used, because the heating time is so short that an insignificant fraction of the generated heat is lost to the water-cooled coil. For larger bars, from about 3-in. diameter upward, the

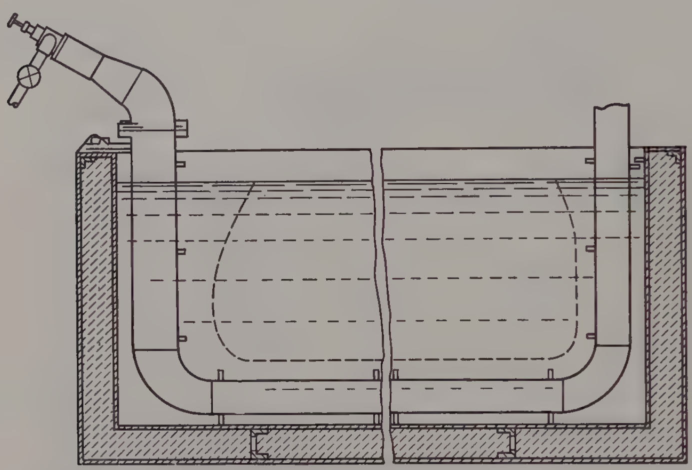


FIG. 129. Salt bath heated by radiant tube.

heating time is long enough to warrant thermal insulation. Insulation is provided in the following manner: A refractory material, usually sillimanite, is rammed in or pressed radially outward and enters an irregular distance between the windings of the coil, as shown in Fig. 130. The refractory material serves several purposes. It constitutes a furnace that keeps the charge warm, it separates the windings of the coil, and it protects the coil from scale that drops off the charge.

Another piece of equipment that is needed in induction heating is a device for holding the charge in the center of the coil and in the correct axial or longitudinal position. An eccentric charge is overheated where the gap is smallest. If a bar is heated in a horizontal position, it is supported by a circumferentially short trough or else by separate longitudinal bars, as shown in Fig. 131. A support of great circumferential length is overheated or even melted.

The coils are wound from flattened copper pipes through which

water is circulated. The water-filled center of the squashed pipe does not reduce its current-carrying capacity because (with high frequencies) the current travels largely along the outer layers (skin effect). With low frequencies water cooling is likewise applied because the currents are heavy for the purpose of rapidity of heating, which is considered to be one of the advantages of induction heating. Round bars are heated in round coils, square bars are heated in almost square coils, and so forth for different cross sections. Alternating magnetic lines passing through air do not heat metal.

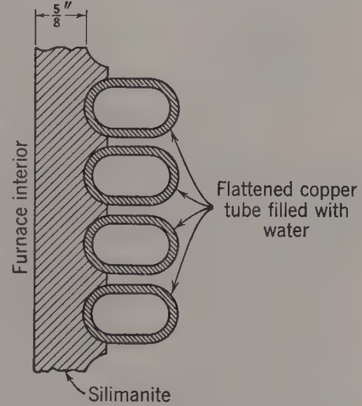


FIG. 130. Refractory lining in inducting coil.

Time in the live coil can be controlled by temperature of the charge, but it is usually controlled by a timing device. If an interruption occurs in the processing equipment, all bars in induction heaters are pulled out and are allowed to cool to room temperature before being charged again. With heating on a time cycle, the bars would be melted if charged hot.

A difference exists between induction heating of magnetic and of non-magnetic materials. A discussion of this difference does not belong in a book on furnaces.

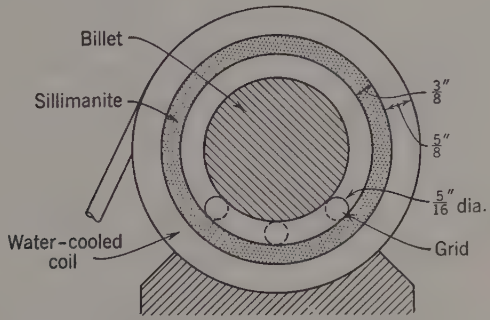


FIG. 131. Method of supporting billet in coil.

Induction heating requires additional, rather expensive equipment. Within the range of industrial furnaces, high frequencies are generated by frequency converters. They are motor generators with few poles on the motor and many poles on the generator. Induction heat-

ing with 60 cps current seriously depresses the power factor unless large capacitors are installed. In 1953 data on first cost were given by the West Penn Power Company and the General Engineering Company:

1. High frequency with motor-generator frequency converters, $150 to $200 per kw.
2. All 60 cycles, $30 to $50 per kw.

These figures include frequency converters for group 1, capacitors for power-factor correction for group 2, and switching, coils, and fundamental handling equipment. They do not include any substation requirements.

In the heating of magnetic steel in ranges between 1¼ in. square to 6 in. square, greatest economy is achieved by the use of two frequencies: low frequency for heating the center, and high frequency for skin heating. The cost for a dual-frequency installation runs between $60 and $100 per kw.

Whereas induction heating is very convenient in mass production, it becomes inconvenient and more expensive if bars of different sizes are to be heated. If, for example, bars of 3 in., 6 in., and 9 in. square and from 4 ft to 15 ft long are to be heated, the following situation arises: Each different cross section requires a different coil with equipment to keep the bar in the center of the coil, whether it be horizontal or vertical or inclined. And each different length requires either a different coil or else provisions for utilizing shorter sections of a long coil. Transformer taps are also needed for impressing the right voltage on a short section of the coil. Devices are needed for holding short bars in the right axial position against end thrust, and these devices may become overheated by induction.

The utilities claim that a net ton of steel can be heated to 2200 F by 300 kw-hr. In practice, that figure runs up to 400 kw-hr.

CHAPTER III

CONTROL OF FURNACE TEMPERATURE

The Problem. The title Control of Furnace Temperature is somewhat misleading, because it is the temperature of the charge, rather than the temperature of the furnace, which needs control. In spite of this serious inaccuracy, the title has been retained in its present form because of its general acceptance by furnace engineers and operators.

Depending upon the nature of the heating process, the aim is either:

1. To bring the outer surface of the charge up to a given temperature[1] and to keep that temperature constant with regard to time until a desired temperature uniformity has been obtained in the charge; or

2. To vary the temperature of the charge according to a given cycle of time.

With either aim, it is desired to keep the temperature quite uniform throughout the charge or stock, that is, with regard to space or location in the furnace. This statement does not apply to continuous furnaces of any type. The reasons for the desirability of reaching a given temperature in the charge and for not exceeding it are quite simple. For each given process and material there is needed a certain minimum temperature which must be attained if the process is to be successful. A temperature much in excess of the minimum not only is a waste of heat but also often produces undesirable results, such as scaling, soft spots, melting, chemical changes, cracking, etc.

The Means for Maintaining a Constant Temperature. Temperature is determined by a balance between heat inflow and heat outflow. If more heat flows into a body than passes out of it, the temperature rises. Exceptions to this rule are caused by latent heat of fusion, vaporization, or molecular rearrangement.

Temperature is increased by turning on more heat; it is lowered by reducing or stopping the supply of heat. An increased supply of electric energy or of fuel and air (up to certain limits) results in

[1] In rapid heating, the temperature of the outside of the charge is raised somewhat above the desired final temperature of the charge and is allowed to drop back; the overheated outer layers bring the center of the charge up to final temperature.

higher temperature, whereas a greatly decreased supply causes a drop in temperature.

Space Uniformity of Temperature. From the foregoing statement it follows that the ideal way of adding heat to the charge consists in imparting an equal amount of heat to each molecule of the charge because, by that method, every particle of the stock would be heated uniformly. The method in which the heating stock is used as a resistor for electric energy (see Chapter II) comes closest to this ideal. If an electric current is passed through a steel bar of constant cross section, the bar is heated rather uniformly. In most cases this procedure is not applicable, and heat is imparted to the surface of the charge from a hotter body, such as a resistor, a flame, molten salt, heated brickwork, or heated gases. Flow of heat is the result of a temperature potential, temperature difference, or heat motive force, and produces a lack of uniformity of temperature inside the charge. As long as the difference between temperature of the surroundings (furnace temperature) and final or desired temperature of stock is not too great, the problem of avoiding local overheating is comparatively simple. As the final temperature is approached, heat flow from the hot body (resistor, products of combustion) to the charge becomes slower, on account of the diminished temperature potential, and there is a chance for temperature equalization in the charge, particularly if its material has high thermal conductivity.

Difficulties arise if the temperature difference between heating element (resistor, products of combustion) and final temperature of the charge is considerable. This condition occurs if the stock is to be heated to temperatures such as 600 F, 1000 F, 1200 F, or even 1400 F. If the material which is to be heated to 1000 F were exposed to a near-by bright flame having a temperature between 2500 and 2800 F, the outside would be much overheated or even melted long before the inside had reached the desired temperature. The danger of local overheating is increased if pieces to be heated are placed too close to inlet ports, burners, or resistors.

Several means of preventing the overheating of the surface of the charge are in use. They are enumerated in the following classification:

(*a*) Turning heat on and off at regular intervals of short duration.

(*b*) Placing a small source of high-temperature heat at a distance from the surface of the charge.

(*c*) Interposing perforated walls (heat ports) between the source of heat and the charge.

(*d*) Placing the charge or the flame in a muffle.

(*e*) Rapid circulation (commonly called "recirculation") of furnace gases, thereby distributing the heat of a small flame through a large amount of furnace gases.

(*f*) Lowering of flame temperature by excess air.

(*g*) Use of "lazy" flame or of low-temperature resistors.

(*h*) Very rapid heating in high temperature, followed by soaking in cooler surroundings.

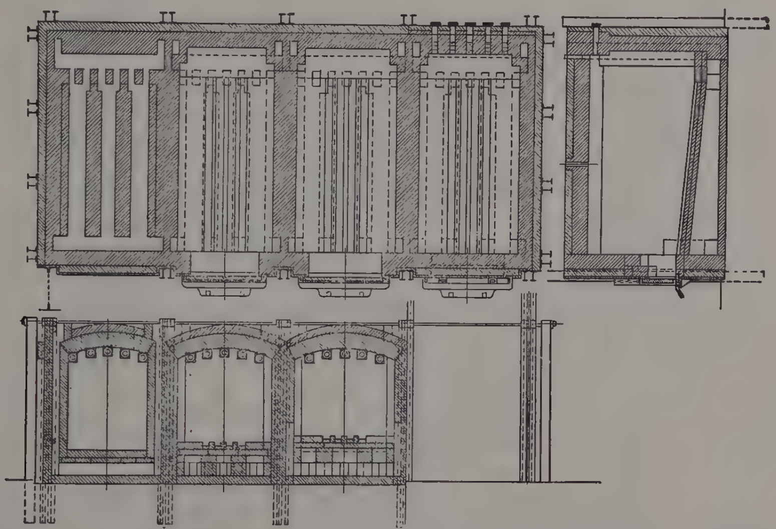


Fig. 132. Gasfired furnace for heating sheets. Uniform temperature distribution in heating chamber is obtained by locating many sources of radiation at a distance from the charge.

Regardless of the final temperature of the charge, the following means is used for securing space uniformity of temperature:

(*i*) Application of heat to all sides of the charge.

These means will now be discussed in detail.

(*a*) *Turning Heat on and off at Intervals.* This topic is discussed below under the heading of Temperature Regulation with Regard to Time.

(*b*) *Placing a Source of High Temperature Heat at a Distance from the Charge.* This method is occasionally employed by itself, but is more often used in conjunction with methods *c*, *d*, and *e*. Its general application can be seen from Fig. 132. The principle is simple and can be illustrated by an analogy. If an electric light is placed low at a short distance above a table, illumination of the table will be far from uniform and will be very intense over a limited area. If

the light is placed at a considerable height, illumination will be less intense and more uniform. This point is well illustrated by the difficulties encountered with early box-type electric furnaces having resistors on sidewalls only. Although the reasons are obvious, it took heat treaters and electroheat engineers a long time to learn why the products frequently varied in such furnaces in spite of automatic temperature control.

(c) *Interposing Heat Ports between the Source of Heat and the Charge.* Heat ports determine the volume of hot gases flowing from and out of variously located openings, the size of which is often adjustable. Heat ports are seen in many furnaces, especially in low-temperature furnaces and in ovens. Heat ports leading from a single-burner combustion chamber into the heating chamber are indicated by black spots in Fig. 133. Although the method of using heat ports is effective in reducing heat transmission to the charge, it must be used with care, because mixing of unconsumed air and unburned combustible often occurs in these ports, with the result that secondary combustion occurs and blowpipe flames issue from the ports. Heat ports above the charge, as in overfired furnaces, produce uniform heating horizontally, but not vertically; the bottom of the charge remains cold. Moreover, heat ports introduce another disadvantage; the combustion chamber is, as a rule, very hot, and heat losses are often incurred because the refractory material of that chamber must be protected against destruction. This protection is secured either by making the walls thin and exposing their outside surfaces to the cool atmosphere or by the installation of high-duty bricks.

The space from which hot gases issue through heat ports is not necessarily a combustion chamber. Recirculated gases also come out from heat ports. The general rule is that each heat port should have approximately the same cross-sectional area that the manifold has. That rule cannot be applied in Fig. 133, because the kinetic energy of the atomizing steam throws the gases a long distance, with the result that the ports must be smallest at greatest distance from the burner. Unless a new installation is a duplicate of a former one, it is advisable to make the size of the heat ports adjustable. In combustion chambers, the adjustment tiles stick to the walls unless both walls and tiles are of super-refractory material (silicon carbide or high alumina).

(d) *Placing the Charge or the Products of Combustion in a Muffle.* If combustion occurs behind a muffle or baffle, the flame cannot impinge on the charge, and cannot radiate directly to the charge. A large part of the radiation is reflected. This principle of physics is

diagrammatically illustrated by the radiation from one particle in Fig. 134. Even if the muffle is infinitely thin, one half of the heat is reflected into the combustion space, as indicated by the double-

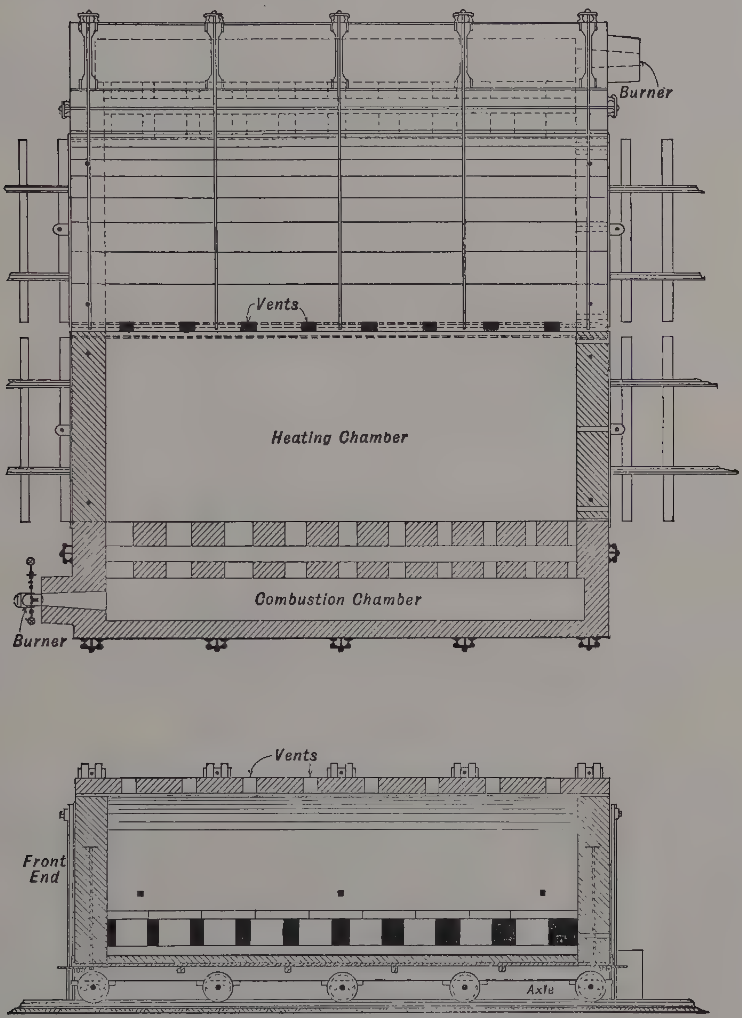


Fig. 133. Indirect-fired car-type annealing furnace, with heat ports for equalizing temperature in heating chamber.

headed arrow. Reradiation evens up the temperature in the combustion space and causes the muffle to glow with a more uniform temperature. A muffle that surrounds the flame for the purpose of equalizing temperature is illustrated in Fig. 135. The material for

muffles and the rate at which heat can safely be transferred through them are discussed in Volume I.

Muffles are often installed for keeping air or products of combustion away from the charge. This purpose is discussed in the next chapter.

(e) *Rapid Circulation of Furnace Gases, with Distribution of the Heat of a Small Flame through a Large Volume of Furnace Gases.* The principle of this method is thoroughly explained by text and

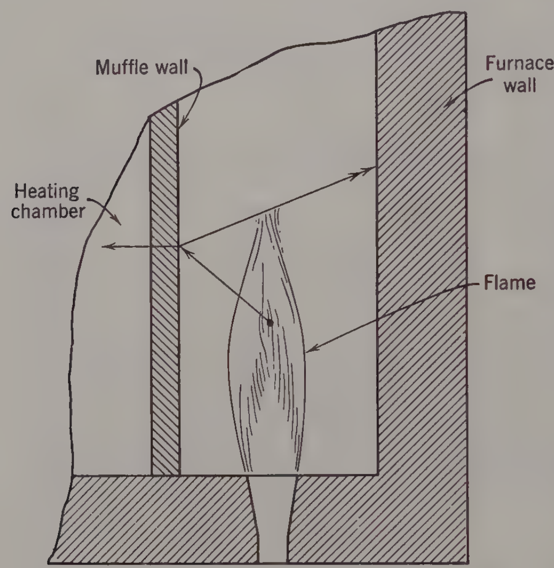


Fig. 134. Temperature-equalizing effect of a muffle wall.

illustrations in Volume I. The method protects against local overheating, because it mixes very hot products of combustion with furnace gases of lower temperature and circulates the mixture over or through the charge. The energy for circulation is occasionally procured from the jet action of a flame that travels at high velocity or from a jet of compressed furnace gases, but comes much more often from a fanblower. Although such blowers (in a few exceptional cases) have been built for temperatures up to 1800 F, their greatest usefulness is found in furnaces (or ovens) that carry temperatures below 1500 F. The lower the furnace temperature, the greater is the usefulness of recirculation. The steel industry uses it for tempering or drawing. The aluminum industry uses it in forge furnaces (aluminum is forged at less than 900° F). Fig. 136 illustrates a forge furnace

for aluminum. The illustration is so well marked that no comment is necessary. Furnaces of this type are used in the steel industry

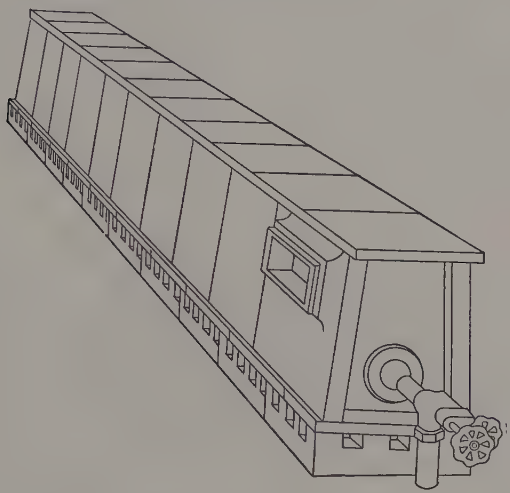


FIG. 135. Muffle around flame. Products of combustion are discharged into heating chamber.

with the slogan "heating without temperature head." In the specifications of low-temperature furnaces or ovens (below 1000 F), the number of recirculations is often stipulated. It runs from eight to ten.

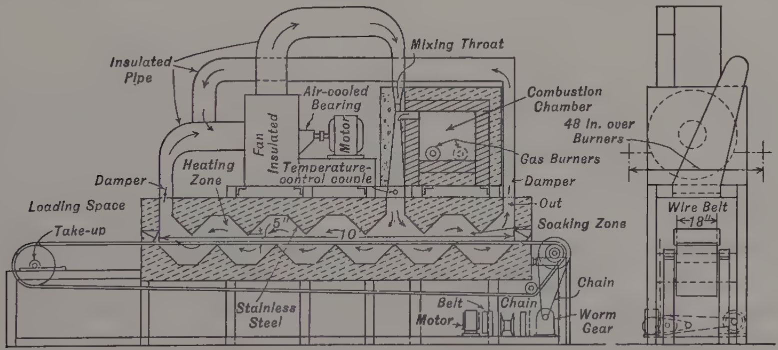


FIG. 136. Continuous furnace with recirculation for low-temperature work.

(*f*) *Addition of Excess Air.* If excess air is mixed with hot products of combustion, the flame is "tempered," which means that the temperature of the gases that contact the charge has been reduced. No

hot blower is needed; the burner blower, if large enough, supplies the excess air. Like recirculation, excess air reduces the danger of non-uniform heating, with this difference: Excess air increases fuel consumption per unit weight of heated material. The increase can be calculated by the use of the curves under Heat Carried out of Furnace by Products of Combustion given in Volume I. Quantitative values for the effects of excess air on uniformity of temperature and on relative fuel consumption were given by Lutherer and Reed in *Metal Progress,* April 1954.

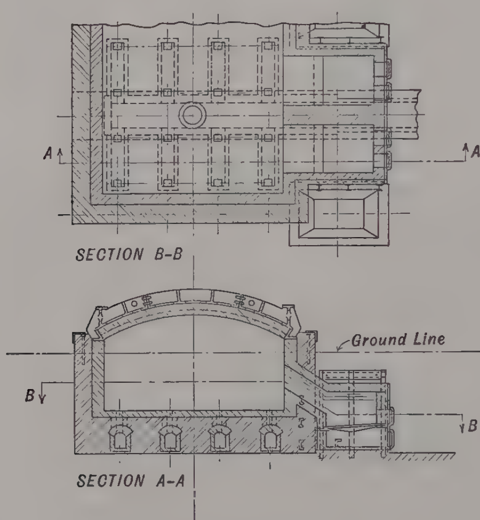


Fig. 137. Annealing pit, designed for uniform temperature.

(*g*) *Use of a Lazy Flame or of Low-temperature Resistors.* Comparatively low temperatures, lying just above the kindling temperature of the fuel, can be obtained by letting air and fuel enter the furnace chamber in parallel streams with approximately equal velocities. Combustion then takes place slowly, by diffusion, and heat is produced through the whole length of the flame travel. Temperatures low enough for the annealing of steel have been obtained by this method even with a rich fuel such as powdered coal. Admission of air in stages has also been used for maintaining a constant, comparatively low temperature all over the hearth.

An annealing pit which combines methods *e* and *g* is illustrated in Fig. 137. Circulation is caused by the direction of flow of the gases and by the well-chosen location of the outlet ports in the hearth. A lazy flame is obtained by incomplete combustion on the grate and

by infiltration of air through the cracks between the sections of the cover. It may be remarked that the purpose of this scheme is frustrated if pieces are piled in front of the inlet port.

Item *h* is discussed in the following (principal) part of the chapter; Item *i* is thoroughly discussed in Volume I.

Temperature Regulation with Regard to Time. The purpose of temperature control is to heat either a whole piece or a portion of a piece to a uniform specified temperature and to hold it a given time at that temperature, if the metallurgical department specified a holding time.

At the turn of the century, the eye of the heater was the pyrometer in this work, and his hand the regulating device. Some excellent heating was done by this method, but lack of skilled craftsmen, the desire to produce good heating at a reduced cost (preferably without labor), and the demand for the greatest uniformity in mass production resulted at first in the installation of pyrometers and finally in the automatic control of temperature by pyrometers. A careful examination of the literature indicates that automatic control of furnace temperature originated in the United States and was applied to gas-heated furnaces as early as 1908. Although the original device was successful, it was not introduced rapidly on a large scale, probably because furnace temperature can be held reasonably constant with gas firing even if no automatic-control mechanism is used, also because the good effects of the new device were not appreciated by the trade, and, finally, because the automotive industry was still in its infancy.

Matters were quite different with electrically heated furnaces of the resistor type, which were introduced in the second decade of the century (about 1917). Hand control of (and by) external resistors was too expensive because of the waste of high-cost electrical energy. Turning electric power on and off at short intervals meant high labor cost. And changing transformer taps was not close enough. In order to sell the resistor furnace, electrical engineers had to invent and perfect a temperature control that would waste neither electric energy nor labor. Such a method consists in automatically turning on and off the supply of electric energy in short intervals.

Automatic temperature control, which is a positive necessity in electrically heated furnaces, was soon advertised as one of the advantages of electric heating, and many electrically heated furnaces were installed solely because they allowed perfectly automatic and reliable temperature control. The incentive for applying automatic temperature-controlling equipment to fuelfired furnaces was very great and brought forth several reliable control instruments.

Before a description of these instruments is given, a fundamental question must be answered, namely, how closely can the temperature of the heating stock or charge be controlled? At first thought, it would appear that perfect control could be attained by placing the temperature-measuring instrument at the point which takes longest to come up to temperature. Two objections must be cited against such an arrangement. (1) The pyrometer may be ruined while the charge is being put into the furnace or is being taken out of it. (2) The outer layers of the charge may be overheated, before the cold-spot pyrometer can exert its control function.

In the heating of certain materials (or shapes) these objections do not exist. If the charge consists of sheets or coils resting on a solid support under a removable furnace hood, a pyrometer is located at the spot presumed to be the coldest. The instrument is not injured in packing or unpacking, because both must be done carefully in any event. Overheating of the outer layers is prevented by locating a second pyrometer at or near the spot that heats up most quickly. The second pyrometer controls furnace temperature, until the cold-spot pyrometer comes up to temperature and takes over.

In the great majority of heating processes the method described above is either impossible or not advisable. In the heating of ingots or of forging billets or of slabs, the coldest spot is somewhere in the solid metal and is, for that reason, inaccessible. In the heating of loose and piled material, such as pipe fittings, bolts, fish hooks, etc., the thermocouple would certainly be damaged or even ruined if buried in the pile. Another difficulty with burying the instrument in the charge arises if the charge moves continuously through the furnace. Traveling pyrometers are not on the market.

In general, the pyrometer must then be placed in a fixed position in the furnace; either in the roof or in a sidewall. The question then arises: How accurately can the temperature of the charge be controlled, if the pyrometer does not contact the charge?

There is no theoretically correct way of telling the temperature difference between the measuring instrument and the coldest part of the charge, but the following method allows a sufficiently close approximation for practical purposes: An experimental run is made, during which the variation of the temperature of the controlling device is observed simultaneously with the temperature of one or more points in the charge. At first these various temperatures are far apart, but, as time passes, they approach each other, as indicated in Fig. 138 which shows the readings of two pyrometers. The time is observed which must elapse on the almost horizontal branch of the upper curve

before the temperature of the test couple at the slowest point of the charge has come up to its final value. From this test, data are secured for future, similar charges in the furnace. If this or a similar precaution is used, the temperature of the stock can indeed be controlled very closely, provided that the charge is piled in the same manner as before and no change is made in the rate of supply of heat.

In the heating of heavy billets, slabs, blooms, and ingots, the same procedure can be, and has been, followed. In a test run, the furnace pyrometer is supplemented by a pyrometer in a hole that was drilled

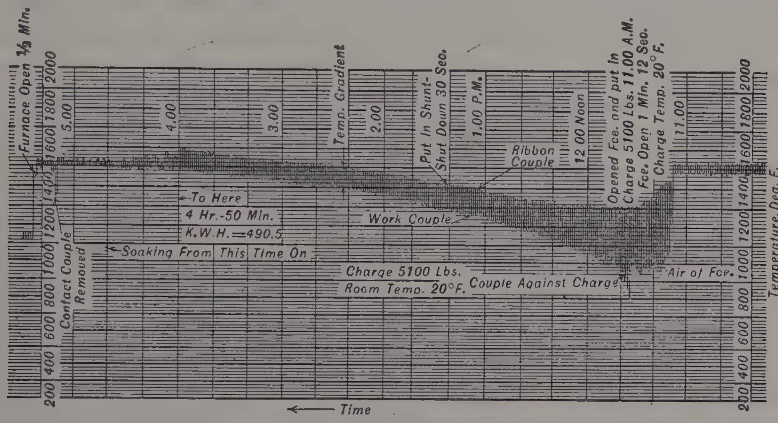


Fig. 138. Time-temperature chart of furnace with automatic control. Upper boundary of curve represents temperature of furnace near resistor ribbon; lower boundary represents, first, temperature of air in open furnace, and, second, temperature of outer surface of charge.

in the material to be heated. With batch-type furnaces, the procedure is comparatively simple. If the material is heated in a continuous furnace, the pyrometer must be removed and reinserted while the piece progresses in the furnace. If the continuous furnace is equipped with water-cooled skids, the pyrometer must not be located near a skid pipe. Even if size of pieces and rate of heating do not remain exactly constant, enough information for practical purposes can be secured from a test run. Experienced furnace builders furnish the information with the furnace.

Engineers have attempted to find something better than the method of making a test and guessing forever after. One of these attempts consists in training a radiation pyrometer directly on the charge. It is, however, impossible to have the radiation pyrometer "see" the coldest part of the charge, and, furthermore, the lenses of radiation pyrometers must be kept clean. In a few cases, radiation pyrometers

come close to indicating the correct temperature, for instance if they are trained through the sidewalls of continuous furnaces which heat slabs or blooms. The sidewalls, at steel level, are not as hot as the roof. The scale on top of the steel is softened and assumes a shiny surface. A radiation pyrometer trained against the top surface measures a mixture of temperature of scale and of roof. Regardless of type of instrument scale falsifies any indication of surface temperature of steel that is being heated to rolling or forging temperature. Test runs with pyrometers in holes take care of the problem, unless the type of fuel is changed. In case of delays at the press or in the mill, the rate of heating is changed, scale becomes thicker and the heater must use his judgment and experience. This is one reason why heaters are paid high wages in spite of automatic controls.

Principles of Control. All governing, regulation, and control requires: (1) A measuring instrument, which is also called the primary element or detector; it measures or at least detects deviations of the controlled quantity from the desired value. (2) A motor or operating element, the action of which is controlled by the detector and which so adjusts the independent variable that the controlled quantity is brought back to the desired value. If the two parts, 1 and 2, are combined into one, the instrument is said to be self-operating.

Although a book on industrial furnaces cannot enter deeply into theory and description of pyrometers and other control apparatus, the highlights will benefit builders, owners, and operators of furnaces.

Pyrometers. For measuring temperatures in industrial furnaces, that is to say within the range of 1000 F to 2500 F, the following instruments are in use: resistance pyrometers, thermocouples, and radiation pyrometers. (Optical pyrometers are used occasionally for checking purposes.) In these instruments, a change in temperature produces a change in electromotive force or a change in current. Resistance pyrometers serve for the low-temperature range. Thermocouples are useful in the whole temperature range that is encountered in industrial furnaces.

A thermocouple consists of two wires of different material. One junction of the wires (the hot junction) is exposed to furnace temperature, while the other junction (the cold junction) is at (or near) room temperature. If the temperature of the cold junction varies, the reading of the indicating instrument must be corrected unless an automatic compensating device has been provided. The following metals are used for thermocouples: iron and Constantan (an alloy of nickel and copper), a combination that can be used up to 1600 F; Chromel and Alumel, up to 2000 F; and platinum and platinum-

rhodium, up to the highest temperatures that occur in industrial furnaces. The wires are corroded in certain gases. Iron is attacked by oxygen; Alumel is corroded by reducing atmospheres. Platinum is embrittled and becomes useless in carbon monoxide. The wires are protected against corrosion by being enclosed in an impervious refractory tube. Evidently, the pyrometer measures the temperature that exists in the protecting tube; and that temperature does not necessarily coincide with furnace temperature. The difference between the two temperatures is made small by reducing the wall thickness of the protecting tube; but then it becomes fragile and not truly impervious. Corrosion is very much slowed down by the protecting tube, but is not entirely eliminated. It pays to remove the thermocouples at regular intervals and to inspect them as well as to test them for accuracy. The more we depend upon automatic control with elimination of furnace labor, the more serious are the results when the controls fail (or "go democratic," in the language of the managers).

Radiation pyrometers are based upon the same principle that underlies thermocouples. In radiation pyrometers the heat rays coming from an opening in the furnace are concentrated on many thermocouples that are connected in series.

Control Mechanisms. The extremely small changes in electromotive force (or in resistance of wire) that result from a variation in furnace temperature are much (very much) too feeble to operate the final control element, which may be a valve or a switch. In other words, temperature control cannot be self-operated, at least not with the means that are at our disposal today. An auxiliary force, called a relay or a servomechanism, must be interposed for the purpose of moving the final controlling element. This latter element may be powered mechanically or pneumatically or hydraulically or electrically. Within each of these possibilities of power, many different designs of control instruments are in existence, and new instruments are forever being offered on the market. It is impossible to describe all of these instruments in the present volume, which is limited to underlying principles. The few examples that have been selected do not necessarily represent the best in existence.

Fig. 139 represents the original method, which is still found today in several furnace installations. The indicating hand or needle of the galvanometer (millivoltmeter) makes contact on the high side or the low side in the same manner as is done by a thermostat that controls room temperature or by a pressure switch that controls the operation of a water pump in rural districts. Fig. 140 diagrammatically

illustrates what is known as a depressor-bar instrument. The needle that indicates temperature is, at regular intervals of time, moved or depressed at right angle to its swinging motion. If furnace temperature is too high, contact is made on one side of a neutral point. If

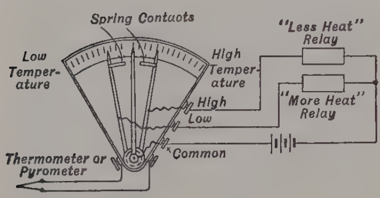


FIG. 139. Diagram of temperature regulator, contact type.

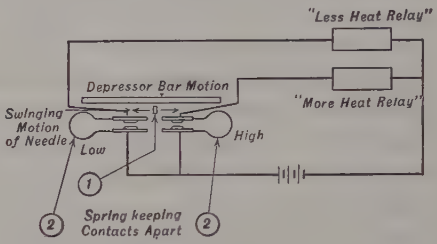


FIG. 140. Diagram of temperature regulator, depressor-bar type.

furnace temperature is too low, contact is made on the other side of the neutral point. In either case, a mechanism is set into motion to bring the furnace temperature back to the desired value.

The control which is accomplished by the mechanisms represented by Figs. 139 and 140 is known as two-position action or as on-and-off control, or, contemptuously, as "saw-tooth" control. Diagrammatically, the effect of the action is illustrated in Fig. 141. This illustra-

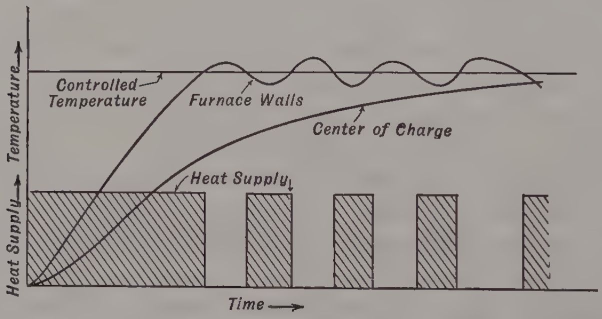


FIG. 141. Diagram of temperature variation produced by on-and-off control.

tion teaches that two-position control does not result in a constant furnace temperature, but produces a hunting (or cycling, or fluctuating, or saw-tooth) temperature. The fluctuation of temperature can be reduced by setting the controls not between "all or nothing" but between less than all and more than nothing, a method that limits the rate of heat input. It takes longer to heat up the furnace after

the introduction of a cold charge; and the idle furnace may be overheated.

A control with smaller fluctuations of temperature is obtained by purposely introducing a deviation from the desired temperature; such a deviation is variously called "droop," or "drift," or in general "load error." Translated into terms of temperature control, these terms mean that, in heating up, the control apparatus begins to reduce heat input at a given temperature but does not wholly shut off the supply of heat until a somewhat higher temperature has been reached. The greater the drift or droop, the smaller the tendency to hunt or oscillate. For many heating operations, the droop is of no consequence in view of the fact that the operator can "reset" the control temperature on the indicating instrument. A close approximation to a constant furnace temperature is obtained by an automatic reset. It consists of a device that, after a disturbance, very slowly returns the temperature to the desired value. The apparatus insures stability (freedom from oscillation) without the drawback of a permanent deviation from the desired temperature.

The electrical circuits for on-and-off, or two-point, control of the types illustrated by Figs. 139 and 140 are very simple. The weak current of the measuring instrument suffices to operate a relay; the relay operates a switch or moves fuel valves and air valves.

With large furnaces, the sudden turning on and off of large amounts of electrical energy is disturbing. For such furnaces proportional control is preferred, although it is more complicated and the instruments are more expensive. Proportional control is based on the following principle: As soon as the pyrometer indicator deviates from the set point (desired temperature), control apparatus is set in motion for the purpose of correcting the supply of heat. The movement of this apparatus is self-limiting because it shuts off its own supply of power by its motion. The temperature must deviate even more before the apparatus can resume its motion. The control apparatus is moved by electric, pneumatic, or hydraulic energy. Since electric energy is available almost everywhere, pneumatic and hydraulic power are usually generated directly at the furnace by electricity. While the commercial equipment for proportional control outwardly is simple, the hidden electric circuits are not, as may be seen from Fig. 142, which illustrates a characteristic circuit. The feeble electromotive force of a thermocouple is balanced in a (Wheatstone-bridge) potentiometer against the constant voltage of a standard cell, which is indicated at the left-hand bottom by (— +). No current flows as long as the temperature remains constant. If the furnace

temperature changes, the electromotive force of the thermocouple changes, and a weak direct current flows in the potentiometer. Since a direct current cannot be amplified proportionally, it is converted into an alternating current by means of a vibrating reed that is energized by 60 cps alternating current. The resulting weak alternating current is transmitted to the two ends of the input transformer. The reactance of this transformer changes the phase, but not the

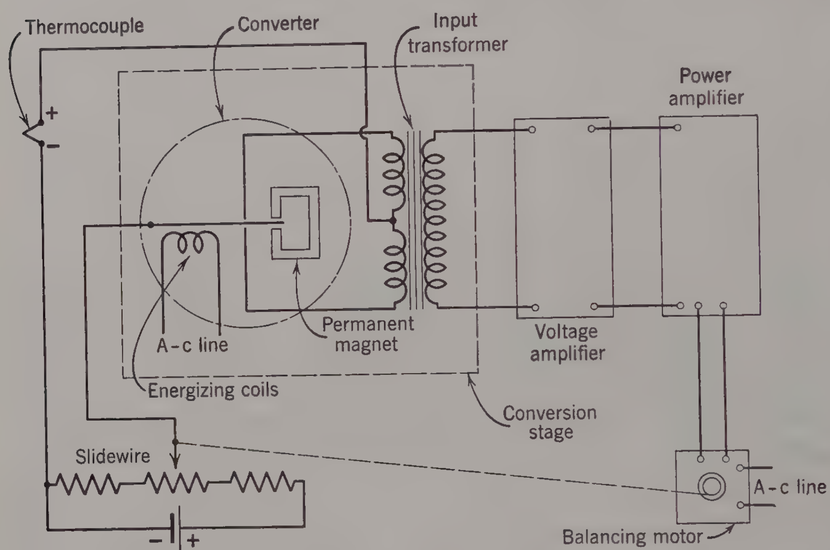


FIG. 142. Diagram of proportional controller. From Minneapolis Honeywell, "Fundamentals of Instrumentation."

frequency, of the current. This current is amplified, usually by electronic tubes, to such an extent that it, in cooperation with the regular supply of electric power, can operate 2 two-phase motors. One of these motors moves the final control element, such as a group of valves, while the other motor moves the slide wire contact to the "null" position in which no current flows. Since the position of the contactor on the slide wire is directly proportional to the temperature, that position can be used as a temperature indicator. All of the wiring, except the leads to the valve-operating motor, is enclosed in an instrument and is visible only after the door of the instrument has been opened.

The circuit illustrated in Fig. 142 is an example of many either identical or similar circuits. In another circuit, the slide wire and the balancing motor have been replaced by two opposing solenoids

which, by their motion, affect the interaction between stator plates and rotor plates. Amplification is obtained by electronic tubes. Amplification by transistors has at this writing (1954) not been commercially introduced.

Temperature controls for industrial furnaces are commonly operated by electric energy. Powering by pneumatic or hydraulic energy is preferred in locations where danger from explosion by sparks exists. In such locations an industrial furnace is out of place.

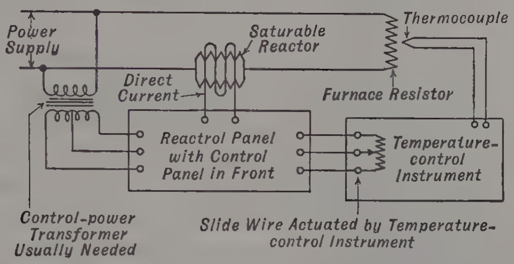


FIG. 143. Diagram of floating control for electrically heated furnaces. Better suited for large furnaces because it eliminates heavy surges in the power line.

It should again be mentioned that the best instrument cannot guarantee uniformity of temperature in the furnace, nor can it overcome the time lag that is caused by the protecting tube around the pyrometer. Neither can the best instrument compensate for changes in heating practice, such as change in size of blooms, method and depth of piling loose material, change in conductivity of charge, and still other factors. Automatic temperature control is at its best in mass production, where *everything* is kept strictly constant.

Adapting the position of a valve to the demand for heat is an easy matter. Adapting the supply of electrical energy continuously to the demand for heat posed a problem. The problem was solved by utilizing the following principle: The furnace resistors (the heating elements) and a transformer are placed in series as shown in Fig. 143. The self-induction or impedance of a sufficiently strong transformer permits only a small fraction of the line voltage to be used in the furnace resistor. If a direct current is made to flow through another winding of the transformer, the core becomes more or less saturated, the molecules are more or less "frozen" in position, the impedance of the transformer is reduced, and more voltage is left to force current through the furnace resistor. Maximum flow of direct current coincides with maximum flow of alternating current through the heating elements.

If a small furnace is equipped with a high-grade temperature control, the control equipment may (and often does) cost more than the furnace. For that reason, simple on-and-off controls are popular for small furnaces. Enough current can flow through the contact pyrometer of Fig. 139 to energize a relay that closes the switch of a solenoid or of a small electric motor. The contact points last a long time if they are made of a non-corrosive metal. A solenoid-operated control mechanism is illustrated by Fig. 144. It consists of a fuel valve and an air valve, both of which are kept open by solenoids against spring force, as long as the power is on. If the pyrometer makes contact on the high side (furnace is too hot), the relay turns the power off and the valves are almost closed by the springs. The same thing happens if the power should go off. It is, of course, not feasible to close the valves entirely, because of the uncertainty in relighting the flame when the valves are opened again, unless pilot flames are provided. The adjustment for minimum flow of fuel and air is made in the control valves by twisting bar-shaped handles, which are visible at the extreme right and left of the illustration. The solenoids are made large enough to operate the valves even if the line voltage drops 25 per cent. This type of furnace control can be used for fuels such as oil or any clean gas.

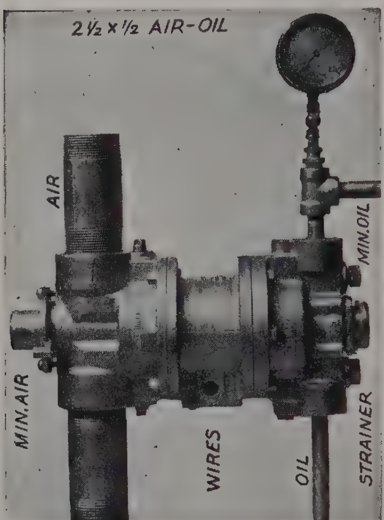


Fig. 144. Simple apparatus for controlling temperature in an oilfired furnace.

Depressor-bar instruments, the principle of which is illustrated by Fig. 140, often make and break electric contact by tilting a mercury switch, a substantially horizontal, hermetically sealed glass tube; in the tube are a few drops of mercury into which two wires dip in one position of the tube. A simple measuring-and-control instrument with a mercury switch is illustrated in Fig. 145. Cam 1, driven by a synchronous motor, operates depressor bar 2, carrying shield 7. In the position shown in the illustration, the mercury switch is closed, heat is being supplied, and the furnace temperature rises. Shield 7 moves up and down, bending the weak leaf spring 3, which offers practically no resistance until the galvanometer needle moves block

5 under abutment 4. Pin 6, blocked against going up, turns shield 7, and pin 8 slides over to the left side of yielding switch 9. On the down stroke, shield 7 touches pin 10 of the mercury switch and tilts it, interrupting the current.

In the control of the temperature of a furnace that is fired by raw producer gas, the thermocouple, the control apparatus, and the valve for combustion air are the same as they are for clean gas and for oil, but the valve that controls the flow of the raw gas must be adapted to the presence of tar and of dust. The valve that is illustrated in

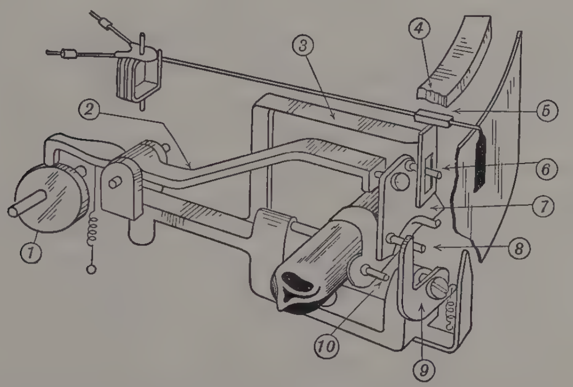


Fig. 145. Simple temperature-control apparatus, using mercury switch. Preferred for small and medium-sized furnaces.

Fig. 62 (Chapter II) is an example of what can be done. Furnace temperature is also controlled in furnaces that are fired by powdered coal. In such installations, the control apparatus regulates the speed of the feeder. If fineness, aeration, and moisture of the coal powder vary, the temperature control still works but the ratio of fuel to air does not remain constant. Coal burning on a grate or on a mechanical stoker does not respond to control as quickly as powdered coal does; nevertheless the temperature of furnaces that are gratefired can be controlled reasonably well. The problem is no different from that of maintaining constant steam pressure in steam generators (boilers).

Number of Control Points. In temperature control, the following questions are encountered: How many pyrometers should be installed, how are they to be connected, and how many burners or resistors should be controlled? In the majority of cases, one thermocouple suffices, with the proviso that occasional tests are made to check the temperature of the charge against the temperature of the control

couple. In long tunnel kilns, two or more couples have been arranged along the path of the ware in the soaking zone and also on opposite sides of the furnace. They are connected in series, with the result that the average temperature controls. While the arrangement in question has been very successful, it requires increased attention because there are more thermocouples to be looked after.

Many large furnaces with rotating hearths are divided into zones, each of which is separately controlled, so that rate of heating and time at temperature may be adapted to the metal or alloy that is being heated. Each zone has its own pyrometer. If the material to be heated is always the same or shows little variation, zoning is either omitted or is restricted to two chambers, one for rapid heating and one for soaking; in this case two pyrometers are provided. The same statements hold for straight-line continuous furnaces, in which, however, only two zones are common. From the standpoint of temperature control, as many as five zones are advantageous. From the standpoint of maintenance, zones are undesirable especially in furnaces with rotating hearths, because the baffle walls between the zones require frequent repairs and rebuilding. Furnaces with zones of different temperatures do not stay circular.

Fig. 146 diagrammatically illustrates temperature control with many control points. The furnace in question is, properly speaking, a series of thirteen furnaces through which a round bar or a tube passes at so high a speed that one series or string of "barrel" furnaces meets the requirements of the rolling mill. The thirteen furnaces are grouped in six zones, with two furnaces in each zone (three furnaces in the group at the discharge end). The arrangement requires extremely rapid heating, in consequence of which the temperature of the individual furnaces, except in those of the last group, must greatly exceed the temperature of the bar or tube. The designers of the furnace decided to measure the temperature of the stock (which has no time to acquire thick scale) and to let it control furnace temperature. A radiation pyrometer was installed ahead of each furnace; in the pyrometer is a therompile, that is to say a number of thermocouples in series. Control is effected by bleeding more or less air from the pneumatic control valve of each furnace. The lenses of the radiation pyrometers must be kept clean. The same equipment is installed in the other five groups or zones.

Additional control devices were installed for the sake of safety. Photoelectric cells reduce the supply of fuel and air, when no stock is passing through the furnace. For each group, one furnace pyrometer limits the supply of explosive mixture to the furnaces of that group.

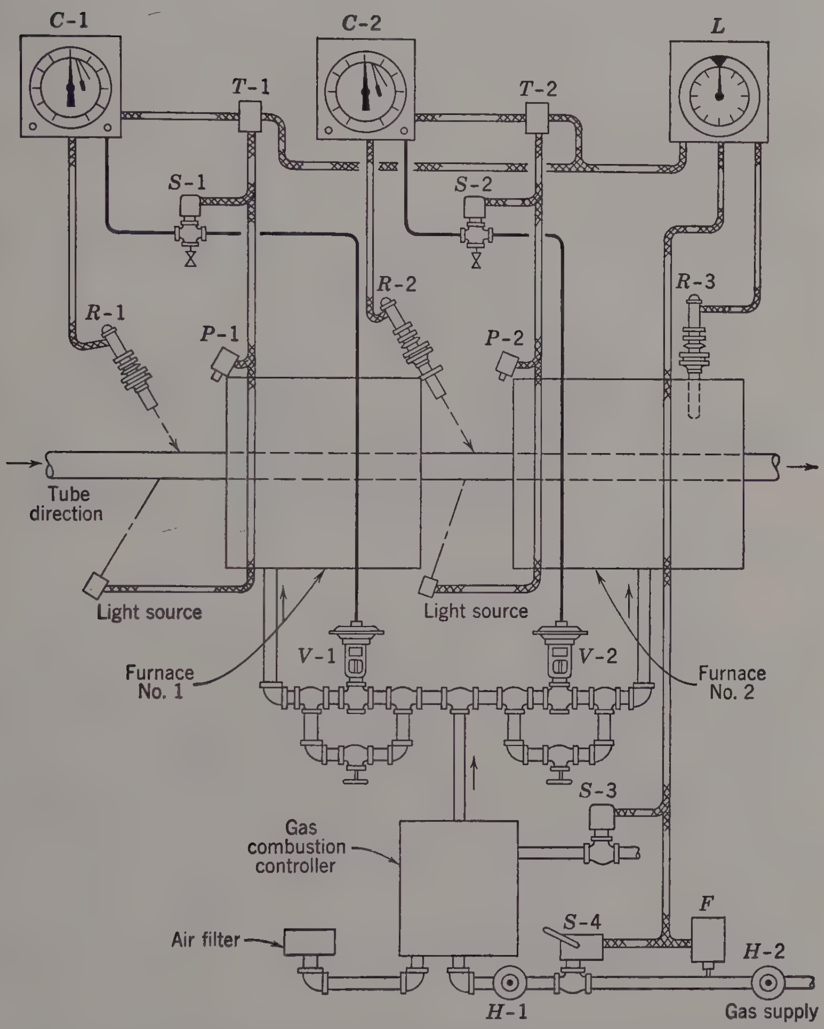


FIG. 146. Diagram of temperature control for barrel furnaces such as is shown in Fig. 283. C = electronic tube temperature controller (recorder); L = electronic furnace temperature-limit controller (indicator); P = photoelectric cell; T = time-delay relay; S-1, S-2 = three-way solenoid valves on instrument air line; S-3 = solenoid air bleed valve; S-4 = safety shutoff gas valve, manual reset type; V = diaphragm motor control valve; R = radiation detecting unit; F = gas-pressure failure switch; H-1 = zone gas-pressure reducing valve; H-2 = zero gas-pressure governor. Courtesy of Selas Corp. of America.

The control is working successfully. Several engineers are of the opinion that the furnace has been "overinstrumented."

Fig. 146 is one example of multiple temperature control in high-speed heating. Other furnaces designed for rapid heating also have multiple controls, as shown in Fig. 147. This pusher-type furnace heats small billets for drop forging, where thinness or even absence of scale is of importance for die life. The arrangement is such that, in effect, the furnace is built up of four separate furnaces, each of which has its own temperature control. Each section is equipped with ten burners, the arrangement of which is indicated in Fig. 148.

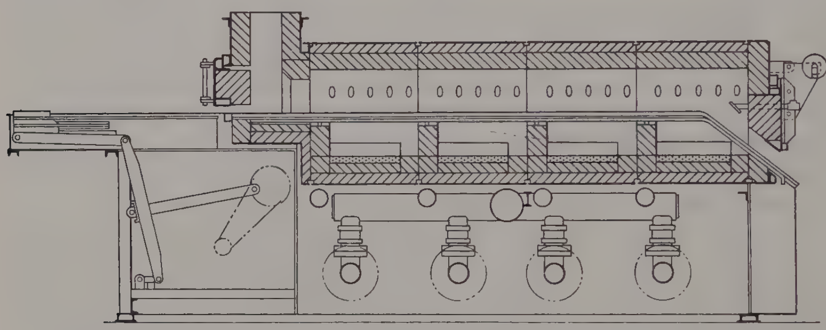


FIG. 147. Continuous furnace with four groups of temperature-controlled burners.

This illustration is a cross section through the same furnace. In the case of delay in the processing equipment, for instance in the drop hammer, the burners are turned off and the vent is closed. Upon restarting, the burners at the discharge end are lighted first. If the delay is extended, the billets that are pushed out first are not immediately processed, but are laid aside to cool before being charged again.

As regards the number of burners or heating elements which should be controlled by one pyrometer, the following remarks are in order: The safest method consists in controlling all burners of the furnace (or the group, as described in the preceding paragraphs). For furnaces of the batch type the statement is self-evident, because stock lying close to an uncontrolled burner would be overheated. One pyrometer controls all burners or resistors in continuous furnaces, unless they are divided into zones, when one pyrometer in each zone controls all the burners of that zone. These statements should not be construed to mean that all burners must be regulated by the same control motor or by the same pneumatic control valve. One pyrometer can operate several control motors or pneumatic control valves, for instance, in a long continuous or automatic furnace.

Program Control. Up to this point only problem 1—keeping constant the temperature of the charge—has been discussed. After a solution had been found for the problem of bringing the temperature of the surface of the charge up to a given value and maintaining it

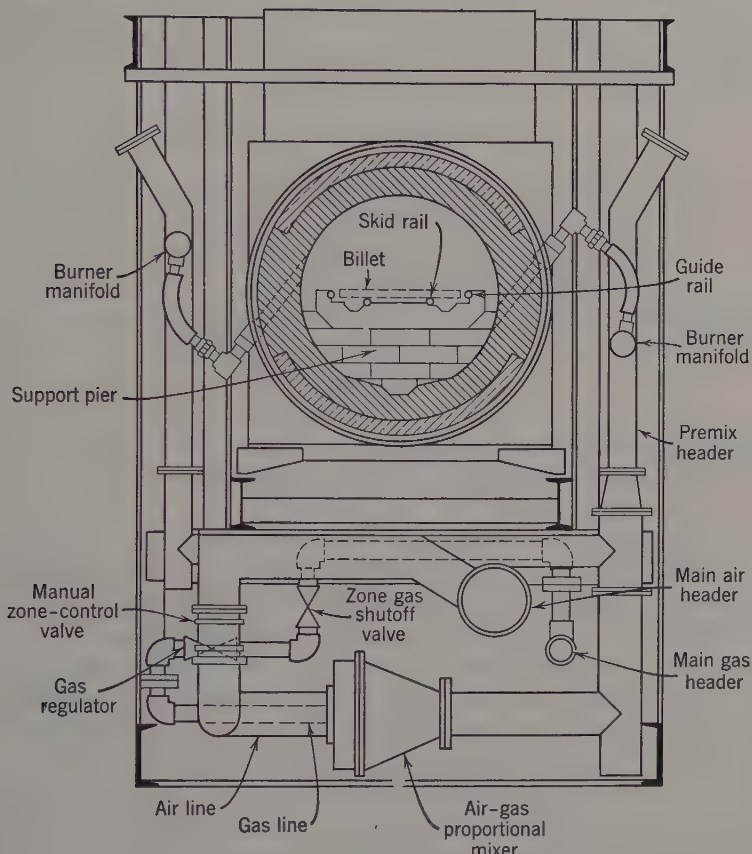


FIG. 148. Cross section through the furnace of Fig. 147.

constant, the problem of automatically varying the temperature, to follow a predetermined law or cycle, offered no insurmountable difficulties.

It will be remembered that, in automatic temperature control, the galvanometer or the potentiometer has a hand adjustment for the temperature (set point or control point) that is to be reached and maintained. All that has to be done to make the temperature follow a given time cycle is to let a cam, driven by a motor or a clock through

suitable speed reducers, move the temperature-controlling adjustment in the required manner. Such a device is shown in Fig. 149. In this instrument a new gear ratio can be readily substituted to change the length of time of a cycle, or a new cam can be susbtituted to change the temperature relations within the cycle. Instead of the cam, an automatic time switch may be used which shuts off the supply of fuel and air or of electric energy after a predetermined time, thereby allowing the cooling of the charge.

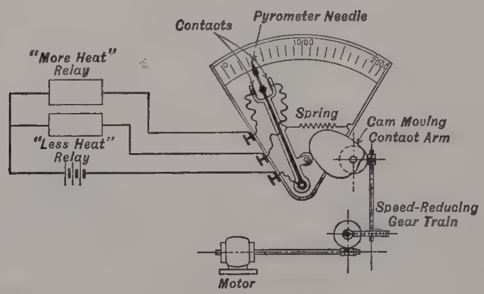


FIG. 149. Diagram of instrument for varying furnace temperature with time according to a predetermined cycle.

The gears and the cam cannot be selected and shaped at random. They must be adapted to the size and to the material of the pieces that are being heated. Ingots of certain tender steels must be heated slowly when cold. The rate of heating may be increased after a given temperature has been reached. And the time that is required to reach that temperature depends upon the diameter of the ingot.

Conclusion. At the conclusion of this chapter a few words of caution may be appropriate. Pyrometers and control equipment have attained a high state of perfection, but that perfection is no guarantee of perfect control of the temperature of the charge in a furnace that is equipped with perfect instruments. As previously mentioned, the location of the pyrometer may be wrong, or its protecting tube may be too thick, or the time that elapses after furnace temperature has been reached may not be right for the charge, or a stream of burning gases may impinge upon the pyrometer, or a base-metal thermocouple may be used too close to its safe temperature, or a thermocouple may burn out, and so forth. Jobbing furnaces that heat pieces of different sizes do not lend themselves to automatic temperature control. In the installation of equipment for control of temperature, the advice of competent furnace engineers and furnace builders should weigh more heavily than the pleas of those who wish to sell control instruments.

CHAPTER IV

CONTROL OF FURNACE ATMOSPHERE

The Effects of Furnace Atmosphere

Although the heating of solids in industrial furnaces is intended to be principally a physical process, chemical reactions between the charge and the surrounding objects cannot be avoided. Chemical reactions, as a rule, proceed more rapidly at elevated temperatures than at room temperatures, and the charge or stock in furnaces is no exception to that rule. If we abstract from the interaction between charge and hearth, there remains the reaction between charge and surrounding medium, which may be solid, liquid, or gaseous. The gaseous medium is commonly referred to as *furnace atmosphere.* Certain solid materials, into which the charge is sometimes packed, release gases at high temperature and thus produce an *atmosphere.*

The chemical reaction between charge and atmosphere varies not only with the temperature but also, quite naturally, with the composition of the charge and with that of the atmosphere that prevails in the furnace. The charge is usually a metal, but is sometimes a ceramic substance. A complete study of the interaction between charge and furnace atmosphere, then, belongs in books on metallurgy and on ceramics, and not in a book on industrial furnaces. In spite of this fact, some of the underlying chemistry must be discussed here for the purpose of understanding the possibilities and limitations of atmosphere control.

Before that explanation is given, it is well to realize that two different kinds of furnace atmospheres are in existence, namely, (1) natural or combustion atmosphere, and (2) artificially prepared atmosphere, which may be gaseous or liquid (if we stretch the word "atmosphere"). The natural or combustion atmosphere contains the products of more or less complete combustion, namely N_2, CO_2, H_2O, CO, H_2, O_2, and sometimes SO_2. Prepared atmospheres consist mainly of N_2, CO, and H_2.

At furnace temperatures, oxygen attacks the common metals and forms oxides or scale. Carbon monoxide and hydrogen reduce the oxides to metal. On the basis of these facts, the terms "oxidizing

atmosphere" and "reducing atmosphere" (both referring to products of combustion) were coined and adopted years ago. Between these two atmospheres, an elusive, supposedly neutral atmosphere was thought to exist.

These names passed into general use before the reactions between metals and products of combustion had been thoroughly investigated. The names of the three atmospheres persist, although it is now known that a neutral combustion atmosphere does not exist and that so-called reducing atmospheres oxidize the common metals. From Fig. 150 it

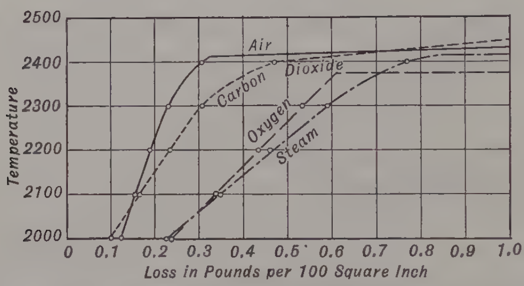


FIG. 150. Effect of variations of temperature and of atmosphere on scaling of steel. (Jominy and Murphy.)

can be seen that not only oxygen but also carbon dioxide and water vapor (steam) are active oxidizers of steel, at least at furnace temperatures. Additional proof for these facts is furnished below.

Although all commonly encountered products of combustion oxidize steel, there is a difference among them with regard to quantity and quality of scale formed. Reducing atmospheres (excess of fuel) form less scale than is formed by oxidizing atmospheres (excess of air), but the scale is tight and adheres firmly. More scale is formed in oxidizing atmospheres, but the scale is loose and more easily removable, unless the steel contains alloying elements such as, for instance, nickel. Even residual nickel causes the scale to be tight and to adhere firmly.

The scaling effect of gases that are supposed to be neutral or reducing is probably caused by transient local dissociation. At all temperatures, some molecules travel at more than average velocity and, in colliding, produce at a microscopically small place a temperature much in excess of the average temperature. Thus, at higher and higher temperatures, an increasing number of molecules of CO_2, H_2O, and O_2 are temporarily dissociated. They reassociate unless a material with great affinity for oxygen is present at the point of dissocia-

tion, in which case the atomic oxygen combines with that material and carbon monoxide and hydrogen are left over. This situation exists even in steel pipes that convey red-hot steam in modern power plants. Scale is formed slowly on the inner surface of the pipes, and a trace of free hydrogen is found at the turbine end of the line.

Scaling by products of combustion is greatly reduced if the charge lies in a quiet, motionless part of the furnace atmosphere and is heated almost entirely by radiation. This condition was closely approached in the old sheet-and-pair furnace, which is illustrated in the last chapter of Volume I. In the rolling of sheets in packs a very thin and adhering scale is needed. If no scale is present, the sheets are welded together by the enormous pressure of the rolls. If the scale is thick, it does not stretch with the sheets; bare spots are formed between patches of scale, and the sheets are welded in the bare spots. In Chapter II mention is made of the fact that products of combustion coming from burners at a low velocity reduce scale formation, and also that low-velocity burners are not popular because they are expensive. The author has observed the formation of scale in identical furnaces, burning the same fuel, but equipped with different burners. In the furnaces that were equipped with low-velocity burners very little scale was formed, and its appearance differed from that of the scale formed in the other furnaces.

The words "reducing atmosphere" bring up the question: If fuel is burned in less than the theoretical quantity of air, can the resulting atmosphere be reducing in fact rather than by name? Experience (backed by theory) has shown that ordinarily this goal cannot be attained, because so much unburned hydrogen and carbon monoxide must be present that furnace temperature cannot be attained unless the combustion air is preheated to an unusually high temperature or heat is imparted to the furnace by other means. A thermochemical theory based on equilibrium constants confirms the findings of experience. The theory of equilibrium constants deals with the ratio of partial pressures of gases in a mixture of gases. Very few owners, builders, and operators of furnaces are inclined to digest the theory of equilibrium constants. It is, therefore, omitted from this book. Another reason for the omission is the great number of treatises on physical chemistry and on protective atmospheres[1] that are on the market.

Many charts and diagrams have been published in which the physical-chemical relations are shown. The charts here offered were

[1] One such book, "Protective Atmospheres," by A. G. Hotchkiss and H. M. Webber, was published by John Wiley & Sons, New York, 1953.

originated by G. Neumann and were published in March 1941 (*Archiv für das Eisenhüttenwesen*). In Fig. 151, which is Neumann's chart for iron, the abscissae are the ratios H_2/H_2O, and the ordinates repre-

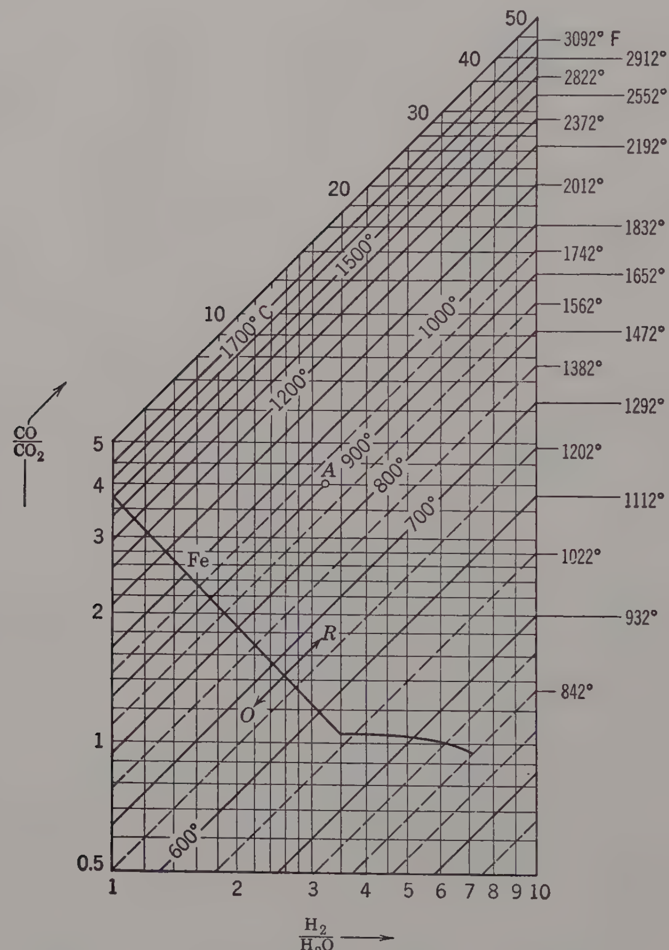


FIG. 151. Reduction and oxidation diagram for iron.

sent the ratios CO/CO_2. The ratios refer to partial pressures at furnace temperature. The inclined lines indicate temperature; in the illustration they are expressed in degrees centigrade. At the right edge, temperatures that lie in the furnace range are given in degrees Fahrenheit. The heavy line is the line of Fe equilibrium between oxidation and reduction. *R* (northeast) means reduction, while *O*

(southwest) means oxidation. A study of the chart reveals that at 2200 F (about 1200 C) steel does not form scale, if, for instance, CO/CO_2 equals 3, and H_2/H_2O exceeds 1.2. Since combustion to CO produces but little heat and unburned hydrogen produces no heat at all, a furnace temperature of 2200 F cannot be attained with these

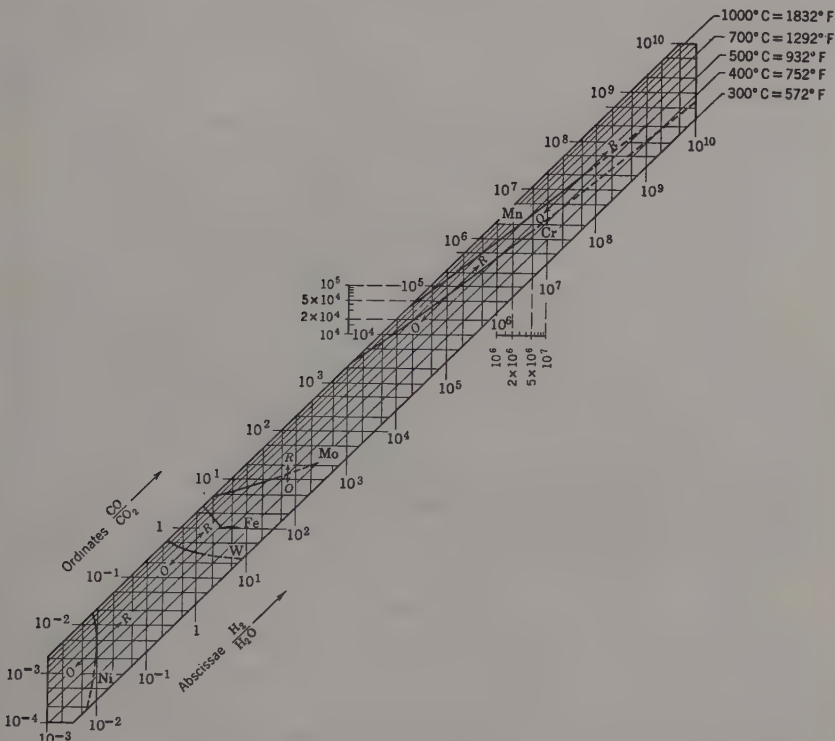


Fig. 152. Reduction and oxidation diagram for various metals.

ratios unless special means are provided for increasing furnace temperature. Such means are combustion in oxygen, or secondary combustion in a regenerator or recuperator which serves for preheating the combustion air, or secondary combustion in a chamber that transmits heat to the heating chamber through a thin muffle wall. Fig. 151 applies to iron and steel only. The affinity for oxygen varies with different metals. In order to express for other metals the relation that is given for iron in Fig. 151, the chart must be extended northeast and southwest. Such an extension was made by Neumann (*loco citato*). His chart is here reproduced as Fig. 152. The scales are logarithmically divided in the following steps: 1, 2, 5, 10, 20, 50,

100, etc. A closer division is given in the auxiliary scales. Among other facts Fig. 152 shows that nickel is not oxidized in a so-called oxidizing combustion atmosphere. Hydrogen may be as low as 1 per cent of water vapor, and carbon monoxide may also be as low as 1 per cent of carbon dioxide, without oxidation of nickel. The equilibrium curve for manganese lies near the other end of the diagram. At furnace temperatures manganese is oxidized, unless the furnace

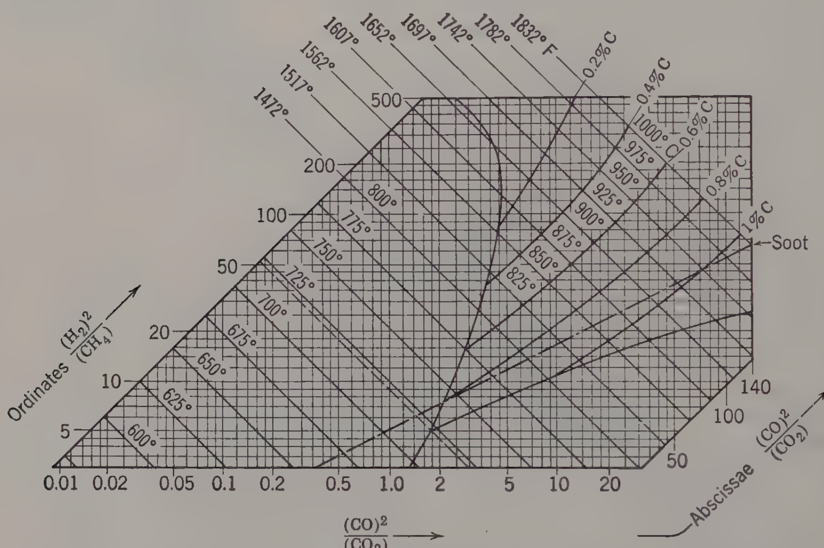


Fig. 153. Carburization and decarburization diagram for steel.

atmosphere consists of pure hydrogen and carbon monoxide, plus an inert gas such as nitrogen. Incidentally, the avidity of manganese for oxygen at high temperatures is utilized for deoxidizing steel in the open-hearth furnace. In an atmosphere of carbon monoxide plus an inert gas, manganese is oxidized at furnace temperatures because of the reaction $2CO = C + CO_2$. Although CO is very stable at elevated temperatures, the previously explained phenomenon of temporary and evanescent dissociation is responsible for this fleeting reaction. The newly formed carbon dioxide is dissociated in the same manner, and the temporarily freed oxygen oxidizes the manganese. Equilibrium curves for other commercially used metals may be entered into Fig. 152.

The author has not been able to find charts that reveal the combined attacks of oxygen and sulphur on metals. A great difference

exists between the actions of oxygen and of sulphur. Nickel, which is resistant to oxidation, combines eagerly with sulphur.

In the heating of steel, oxidation is not the only problem. Another problem exists, namely, carburization and decarburization. The latter action is often abbreviated to "decarb." Carburization, which means increase of carbon content, is practiced for the purpose of producing a hard surface on mild steel. Decarburization, which means reduction of carbon content, is usually considered to be harmful because the surfaces of the pieces of steel become soft. At high temperatures oxidation and decarburization of steel occur simultaneously in combustion atmospheres. The higher the temperature, the greater is the affinity of carbon for oxygen, in comparison with the affinity of iron for oxygen. If this were not so, the blast furnace would not work.

In the same *Archiv* Neumann also published a chart for carburization and decarburization, from which Fig. 153 was adapted. The coordinates in this chart differ from those used in the oxidation and reduction charts. The right-hand top of Fig. 153 contains a set of curves for steel with various carbon contents. To the northwest of each curve, decarburization takes place. To the southeast of each curve the steel is carburized. The influence of carbon content and of temperature shows very plainly.

The charts in Figs. 151, 152, and 153 are based upon equilibrium conditions. Attaining equilibrium requires a long time, much more time than is available in commercial practice. For that reason, all equilibrium charts can serve as a general guide only.

All of the facts expounded above lead to the following conclusions: Most metals are oxidized in natural furnace atmospheres. Steel, especially high-carbon steel, is not only oxidized but also decarburized at high temperatures. If oxidation and decarburization are to be avoided, steel must be heated in a specially prepared, protective atmosphere. The same statement (with the exception of decarburization) is true for most of the commercially used metals.

Control of Natural Furnace Atmospheres (Combustion Control). Since most metals are oxidized in natural combustion atmospheres, the question may well be asked: Why bother with combustion control? Several answers can be given to the question. Fuel consumption per unit weight of heated material is lowest if the fuel-to-air ratio is close to the theoretical value. And the nature of the scale varies with the fuel-to-air ratio. It must, however, be emphasized that the thickness of the scale, or the weight of scale formed on unit surface of the charge, depends more on furnace temperature and time of exposure than on the composition of the products of combustion. Some owners of

furnaces have the mistaken idea that adjusting the burners for excess fuel will materially reduce the formation of scale, in spite of high furnace temperature and of long exposure.

The oldest means of controlling a natural furnace atmosphere is to let the eye of the heater (possibly guided by occasional analysis of flue gases) be the measuring instrument, and his hand the control mechanism which adjusts air flow to fuel flow until the furnace interior "looks right." With some fuels and with some burner types, the heater can indeed come rather close to the desired goal; but with fuels which are rich in hydrogen and with premixing burners, correct judgment by the eye alone is impossible, except when the thickness of scale on the heated product (after its discharge from the furnace) is watched.

In industrial furnaces, automatic pressure control is a prerequisite for automatic combustion control. As explained in Volume I, a slight pressure, usually $\frac{1}{40}$ in. of water column, is maintained at the level of the hearth in every metal-heating furnace. A slight draft or vacuum in the heating chamber sucks in cold air, which cools the charge and increases oxidation. Automatic pressure control is too expensive for small furnaces. In such furnaces, the furnace pressure is measured very simply. The slight pressure suffices to shoot hot gases out from a small hole in the door, near the hearth. The jet of gases coming through the hole is frequently called a "stinger." Its length is a measure of furnace pressure. Any fine dust, including cigarette smoke, dropped in front of the hole or blown across it increases the visibility of the stinger. Large and important furnaces are equipped with apparatus for keeping furnace pressure constant. The equipment is described in Volume I. The principle of pressure control is identical with the principle of temperature control with the single exception that a pressure-sensitive instrument takes the place of a temperature-sensitive instrument. Among pressure-sensitive instruments are bells floating in oil and diaphragms. The slight displacement of the instrument is amplified electrically or hydraulically or pneumatically.

A number of means are available for automatic combustion control (which is synonymous with control of natural furnace atmosphere). They are (1) interconnection of equipment that controls flow of air and of fuel, (2) control of one component of the fuel-air mixture by the rate of flow of the other component, (3) control by composition of products of combustion (flue-gas analysis).

Accurate combustion control is most easily attained with clean gaseous fuels. Dirty gases and liquid fuels are more difficult to handle proportionally. Accuracy is lowest with solid fuels. In any event,

extreme accuracy is not necessary, because a few per cent of excess or deficiency of air have very little effect upon fuel economy and upon

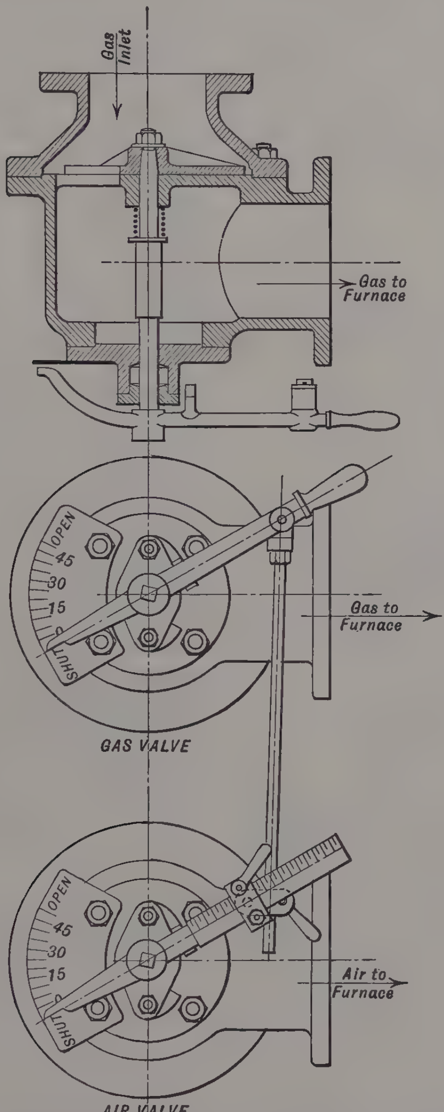


FIG. 154. Interconnected air and gas valves with adjustment for variation of relative openings.

oxidation of charge. Combustion control means maintaining the ratio of fuel to air constant at all rates of firing. Unless combustion is

completed in the burner tile, furnace atmosphere is not constant, but varies along the travel of the flame.

Combustion Control by Interconnected Valves. Interconnected valves are illustrated in Figs. 154 and 155. The valves of Fig. 154 are homemade and do not assure proportionality at all rates of firing or with different fuels. The valves of Fig. 155 are on the market and assure proportionality, if certain precautions are observed. They are (1) constant pressure of fuel ahead of control valve, (2) constant pressure of air ahead of control valve, (3) constant temperature of fuel and of air. The last condition is most important for oil fuel. Moisture in air and in gaseous fuels is of minor importance. Variation in calorific value of fuel has a decidedly great effect, but is ordinarily not expected. The valves of Fig. 155 are based upon providing strictly proportional openings by rotation. The axial length of one opening is adjustable for the purpose of adapting the valves to different fuels. For liquid fuels a valve of small diameter is provided. Equipment for keeping pressure constant (ahead of the proportioning valve) is well known and needs no description.

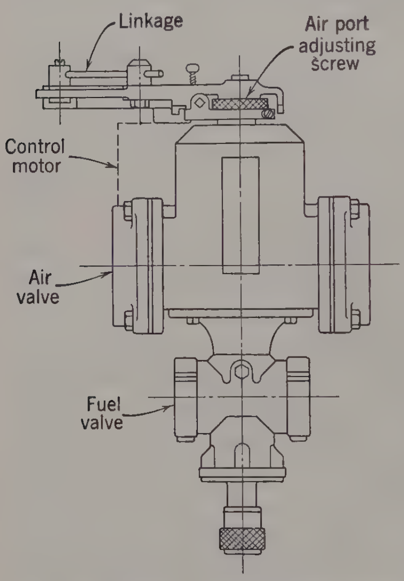


Fig. 155. Coaxial proportioning valve for fuel and air. The fuel-to-air ratio, once adjusted, remains constant. Courtesy of North American Mfg. Co.

After having passed through the interconnected valves, fuel and air are delivered to the burners through separate pipes, which should be so large that but little throttling effect can exist in either line. If the fuel is a clean gas, it may be mixed with the air immediately beyond the proportioning valve. In that case the pressure must be high enough to prevent flashback. It is good engineering to take air and gas into the interconnected valve equipment at atmospheric pressure and to compress the mixture by a pump, which is usually of the multivane displacement type but which may be a centrifugal blower.

Although the equipment for proportional mixing is extraneous to the furnace, a brief description will be of assistance because it illustrates interconnected valves of another design. In Fig. 156 fuel enters

through a gas regulator, which is often called a "zero governor," and flows through chamber C. Air enters through a fine screen, which acts as a filter, and flows through chamber B. Spaces B and C are separated by a central partition at right angles to the illustration. The partition does not show in the illustration. The space A is connected with the suction of the pump. The air filter offers resistance

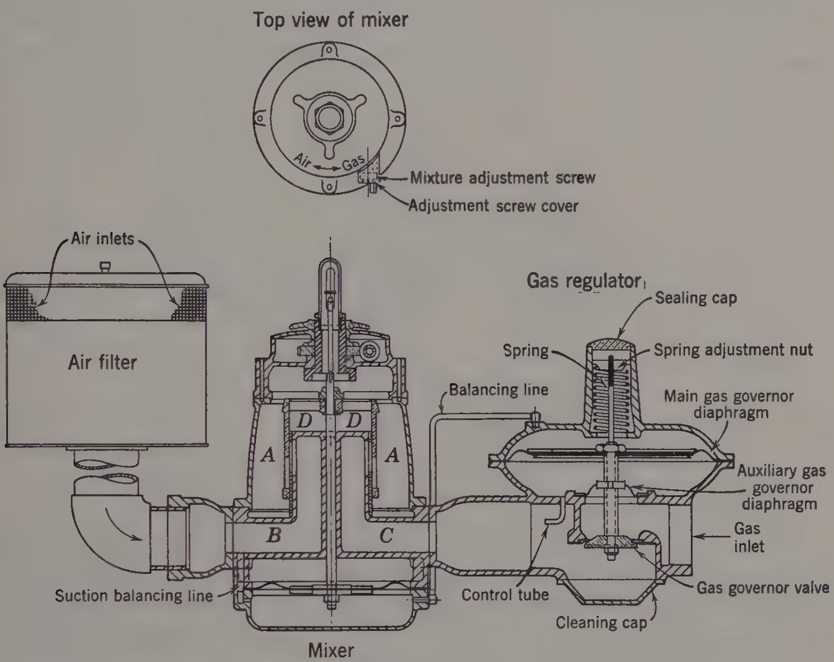


FIG. 156. Proportional mixer with gas regulator and air filter. Courtesy of Selas Corp. of America.

to flow, and dirt accumulation causes the resistance to grow with time. A balance line from the filter to the gas governor causes the pressures of gas and of air to be equal at entrance to the mixing valve. A constant pressure difference between both spaces (B and C) and space A is maintained by a diaphragm at the bottom of the proportioning valves, and the flow from B and C is symmetrical. In consequence, flow from B and C into A is proportional to the free areas in the sleeves. The gas-to-air ratio is adjusted by twisting the movable sleeve D. The twisting is accomplished by turning a worm that is shown near the top of the illustration. The pump between proportioning valve and furnace generates a predetermined constant pressure regardless of the number of burners that are in operation. Centrifugal

blowers can be designed to maintain an almost constant pressure in spite of variations in rate of delivery. Displacement blowers deliver a given volume per revolution. The delivery pressure is maintained at a constant value either by speed variation or by a pressure-controlled by-pass (run-around). Variation of speed is cumbersome and expensive if the pump is driven by an alternating-current motor. For that reason, the by-pass is usually preferred. The by-passed mixture becomes hot, especially so if most of the pumped mixture is by-passed. The pump must be so designed and built that no sparks can be produced in it.

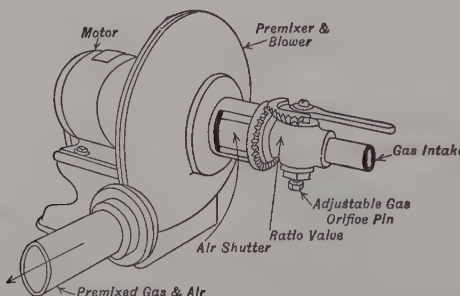


FIG. 157. Non-symmetrical mixer for air and gas.

In the comments on Figs. 155 and 156, stress was laid on symmetry. Interconnected but non-symmetrical valves are shown in Fig. 157. In view of the above statements on combustion control for industrial furnaces, the apparatus is probably good enough. However, it does not maintain a constant gas-to-air ratio.

Combustion control has also been attained by gearing together separate displacement pumps for fuel and air. Adjustment of the fuel-to-air ratio is accomplished by changing the gear ratio. If oil or tar serves as fuel, a screw pump or a gear pump is installed.

Combustion Control by Flue-Gas Analysis. Measuring instruments determine content of carbon dioxide or of oxygen. Or else they measure specific gravity or thermal conductivity of products of combustion. The method by which any one of these indications controls the ratio of fuel to air has not found favor in the operation of metal-heating furnaces. Flue-gas analysis is used as a guide in adjusting the fuel-to-air ratio in open-hearth furnaces. They are leaky structures which become more leaky as time goes on. More and more air leaks in, and the adjusted fuel-to-air ratio does not stay put. The actual ratio differs from the ratio that is indicated by the instruments.

Combustion Control in Which One Component Determines the Flow of the Other Component. In Chapter II, inspirators and proportional mixers are described. In the present chapter the question to be discussed is this: How accurately does an aspirating mixer maintain the desired gas-to-air ratio under varying conditions? Table XII, which was taken from a publication of the Surface Combustion Corporation,

TABLE XII

Low-Pressure Inspirator

Pressure		Gas Flow,	Per Cent in Flue Gas		
Air, psi	Mixture, in. of Water	cu ft per hr	CO_2	O_2	CO
1.0	6.0	720	11.8	0.0	0.0
.78	4.7	635	11.4	0.2	0.0
.55	3.7	565	11.4	0.1	0.0
.35	2.1	424	11.4	0.2	0.0
.29	1.7	389	11.5	0.1	0.0
.12	.8	254	11.3	0.1	0.0
.10	.6	229	11.0	0.0	0.0

High-Pressure Inspirator

Pressure		Gas Flow,	Per Cent in Flue Gas		
Gas, psi	Mixture, in. of Water	cu ft per hr	CO_2	O_2	CO
9.38	4.4	481	10.6	0.1	0.0
7.44	3.6	438	10.7	0.0	0.0
5.89	2.8	375	10.7	0.1	0.0
4.14	2.3	333	10.6	0.0	0.1
2.90	1.35	254	10.5	0.0	0.2
1.12	0.50	164	10.5	0.0	0.2

answers the question from a practical standpoint. The constancy of the flue-gas composition proves that the gas-to-air ratio remains constant. High-pressure inspirators are illustrated in Figs. 52, 53, and 58. Low-pressure inspirators are illustrated in Figs. 66 and 67.

Inspirators are jet pumps, and the theory of jet pumps applies to inspirators. The simplest jet pump is one in which the pressures at inlet and outlet are equal and in which no friction occurs between the flowing fluid and the walls. In other words, the pressure at the end of the Venturi or diffusor equals the pressure in the mixer head (entrance), and there is no friction in the cylindrical, or almost cylindrical, mixing tube or in the diffusor which leads to the outlet. In this case the momentum equation given on page 74 applies and suffices.

However, the momentum equation furnishes no information on the best diameter and length of mixing tube and of diffusor. If the inspirator were to serve for mixing only, regardless of other conditions, the diameter of the mixing tube could be selected at random within wide limits. The velocity is low if the tube is large for the rate of flow; only a low pressure of the driving fluid is then needed. Although this is a desirable feature, the dimensions of the inspirator are determined by other considerations. The mixing tube has a length that lies between 6 and 8 tube diameters, and the Venturi diffusor beyond the mixing tube has an included cone angle of 7 degrees. The inspirator and the piping become too large and too expensive if a low pressure of the driving fluid is the main consideration. Moreover, the resulting mixture velocity must be high enough at the burner or burners to prevent flashback even at the lowest rate of firing. The sizes of commercial inspirators are determined by competition between manufacturers because the sizes are a compromise between conflicting conditions (first cost and continued cost of pumping). In the manufacture of inspirators several things are of importance: In high-pressure inspirators, the high-pressure jet must be central and coaxial with the mixing tube. The distance of the spud from the mixing tube is of importance, and the internal surfaces of the mixer must be very smooth.

The simple momentum equation fails if the pressure at the discharge end exceeds the intake pressure. This condition exists in all those inspirators which serve a multiplicity of burners. A higher gas pressure is then needed for overcoming the pressure difference and the frictional resistance of the piping. The primary function of air shutters on individual inspirator burners is to prevent air flow through the burner openings while the furnace is shut down overnight. The shutters are sometimes used for adjusting the ratio of gas to air.

As mentioned in Chapter II, mixers in which the air inspirates the gas are known as proportional mixers. They never serve individual burners, because each mixer needs a "zero governor" which admits fuel gas at atmospheric pressure. The combination of mixer, zero governor, piping, and burner is illustrated in Fig. 158. Designs of mixers and of burners may change, but the general arrangement remains the same. In general, proportional mixers are considered to be less accurate than high-pressure inspirators in maintaining a constant ratio of fuel gas to air. However, Table XII proves that the ratio can be maintained at a constant value, at least under laboratory conditions. All proportional mixers have a device for adjustment of fuel-to-air ratio, either by changing the opening between zero governor and throat of Venturi tube, as illustrated in Figs. 66 and 67, or else

by changing the cross section of the throat of the Venturi tube. The latter device is illustrated in Fig. 159. The greater the diameter of the inserted rod, the greater is the vacuum that sucks fuel gas into the throat. All of these adjusting devices are useful for "field" adjust-

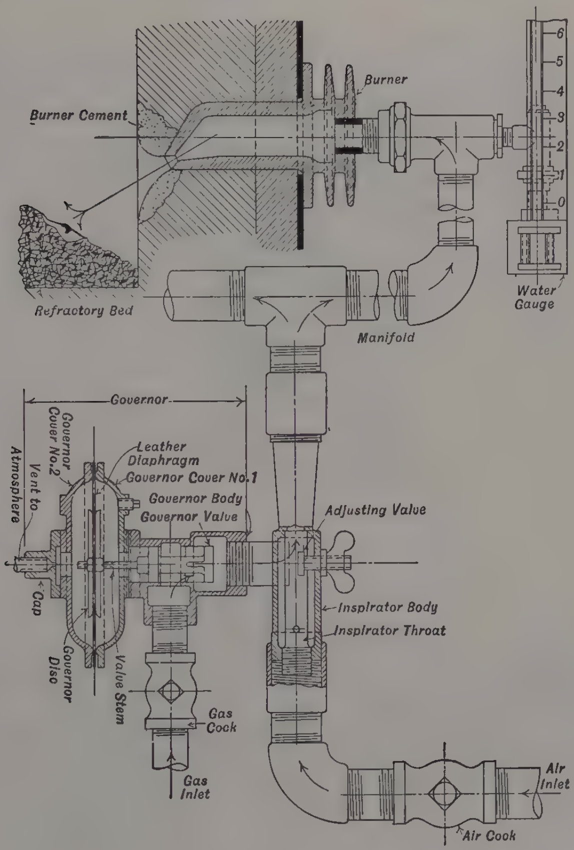


FIG. 158. Diagrammatic assembly of proportional mixer, zero governor, piping, and burner.

ments. The resistance of the piping between mixer and burners is not known by the manufacturer of the mixers; for that reason, adjusting devices are incorporated in the mixer design. Some of these adjusting means prevent the fuel-to-air ratio from being constant over the whole range of firing. As previously stated, small variations from the correct ratio do no harm in industrial furnaces. If proportionality is essential at all rates of flow several means are in existence for maintaining proportionality. Fig. 160 illustrates one such device. A pipe,

cut diagonally, reaches into the diffusor. Depending upon its rotational position, the pipe either increases or decreases the pressure on the diaphragm of the gas governor. The location of the control pipe along the axis of the diffusor is of importance; it is determined by experiment in the field.

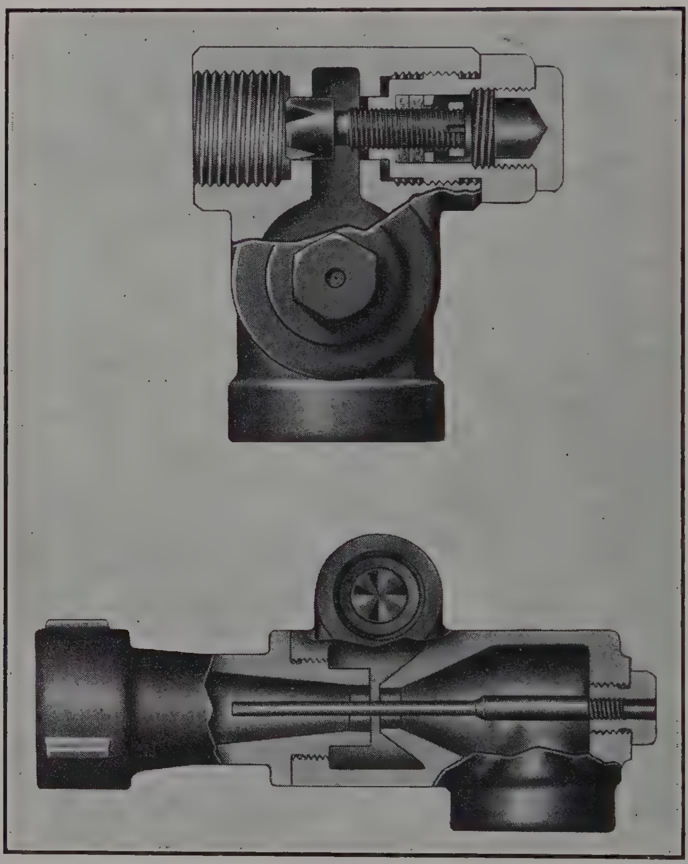


FIG. 159. Proportional mixer that maintains constant ratio of fuel to air at all rates of flow. Courtesy of North American Mfg. Co.

The principle of causing the flow of one component of the combustible mixture to control the rate of flow of the other component has been embodied in equipment that looks very different from that discussed in the preceding paragraphs. Fig. 161 illustrates such equipment. It is based on the fact that a fluid passing through an orifice produces a pressure drop which is practically proportional to the square of the velocity of flow, provided the fluid has a low viscosity. In the

illustration, air flows through the pipe shown on the left, while fuel gas flows through the one shown on the right. Each pipe carries an orifice; and the pressure drops through the two orifices, by acting on diaphragms or floating bells, cause forces which are pitted against each other. The orifices must be selected so that, with the correct ratio of gas to air, the forces caused by the pressure differences of the two orifices counterbalance each other. If either too much or too little air is flowing in proportion to the flow of gas, the forces become unbalanced and a relay is set into motion. In the illustration, contact is made on one side or on the other of a sensitive electric switch. By means of an electric relay, an electric motor is started in one direction or the other and turns a butterfly valve, thereby adjusting the air flow until the correct ratio of gas to air has again

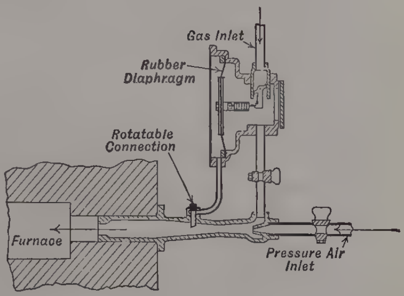


FIG. 160. Proportional mixer of the inspirator type. Proportionality is maintained over the whole range of flow.

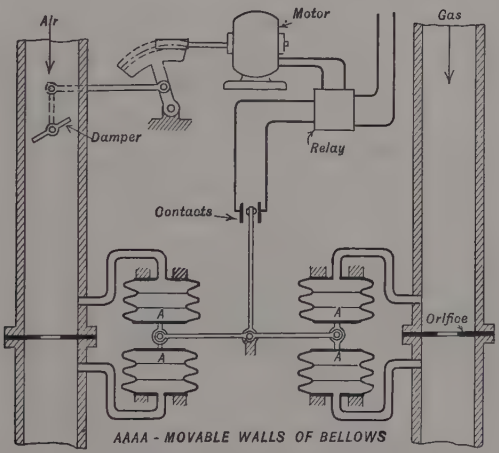


FIG. 161. Diagram of proportioning meter, based on equality of pressure drops through orifices.

been obtained. The various parts are so clearly shown in the illustration that no further comment is necessary. The ratio of gas to air can be varied by changing the size of either one of the two orifice plates. If a variation of adjustment is to be obtained while the equip-

ment is in operation, one of the orifices can be made adjustable, for instance, by a slide which can be operated from the outside.

Fig. 161 illustrates a principle only. The apparatus actually in use looks quite different. The control equipment shown in Fig. 161 would cause never-ending fluctuations between too much fuel and too little fuel. The fluctuations can be eliminated by the instrumentation that is explained in the preceding chapter. Instead of the bellows, diaphragms or else bells floating in oil are often preferred. Electric potentiometer control with electronic amplification is commonly used. Adjustment of the valves by compressed air and by oil under pressure is frequently seen. If the fuel gas is dirty, means must be provided for cleaning the fuel orifice, because accumulations ahead of the orifice change the coefficient of flow. Evidently, Venturi tubes may be substituted for the orifices.

In Fig. 161 the gas orifice may be replaced by a valve, the opening of which is controlled by the pressure difference across the air orifice. This is actually done, if oil serves as fuel. In many oil burners (see Chapter II), ratio control is built into the burner. For large and important furnaces with several burners the scheme mentioned at the beginning of this paragraph is preferred. The temperature-control valve determines the air pressure ahead of the burners. This air pressure acts on a diaphragm, the stem of which controls the opening of a valve in the oil line. Such a combination is illustrated by Fig. 162. The pressure of the air between the temperature-control valve and the burners reaches the top of the diaphragm through the opening that is marked "Impulse Connection." The pressure of the oil that has passed through the valve at the bottom of the stem pushes upward on another diaphragm that tends to close the oil valve. The relative sizes of the diaphragms determine the ratio of oil pressure to air pressure. The relative sizes of openings for oil and air at the burners determine the oil-to-air ratio. Pressure gages and a thermometer for oil are provided as indicated in the illustration. An oil strainer must be inserted ahead of the ratio control.

If tar serves as fuel, the correct fuel-to-air ratio is sometimes maintained constant by letting the flow of air control the speed of the tar pump (screw pump or gear pump). It is difficult to find a screw pump or a gear pump that is small enough for the average industrial furnace. The delivery of a screw pump or a gear pump is proportional to its speed. The flow of air through an orifice is proportional to the square root of the pressure drop. These facts must be kept in mind in designing a device in which the flow of air through an orifice controls the speed of a fuel pump.

The principle illustrated by Fig. 161 and similar principles are very widely used in combustion control for gaseous and liquid fuels. Very elaborate control boards, based on these principles, are adjuncts to almost all large and important furnaces.

Up to this point no distinction has been made between furnaces with individual burners and those with a multiplicity of burners. The num-

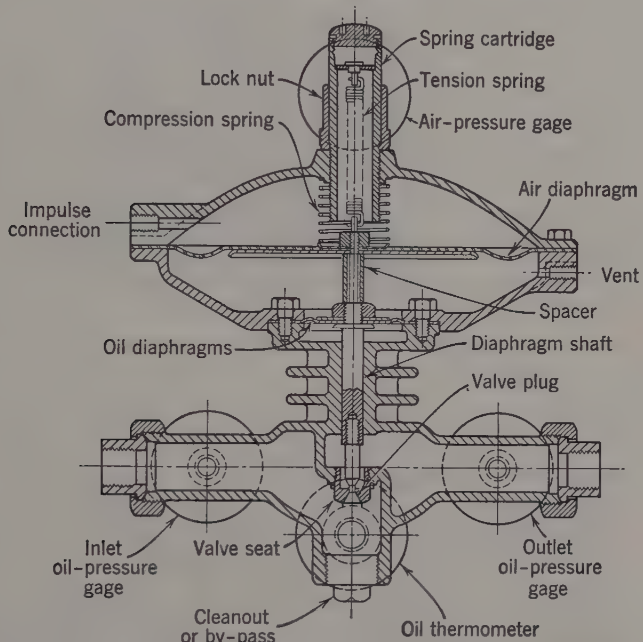


FIG. 162. Oil-air ratio regulator. Courtesy of North American Mfg. Co.

ber of burners causes no difference if the correct explosive mixture is delivered to each burner from a common header; if, on the other hand, manually controlled mixers or two-pipe systems are used, atmosphere control becomes difficult as happens when more than one burner is used. The difficulty is this: The flue gases leaving the furnace may have the correct composition (practically no oxygen and a very small amount of combustible), and yet the gases may be very oxidizing in front of some of the burners, the difference being made up by a strongly reducing atmosphere coming from the rest of the burners.

If the air-to-fuel ratio is controlled ahead of the furnace and if the openings (in the burners) for air and fuel always have the same ratio regardless of the rate of firing, combustion control is perfect even if some burners fire harder than others. However, conditions are some-

times such that automatic control of combustion is extremely difficult, if not impossible. Fig. 163 illustrates this statement.

The furnace there shown is fired by hot producer gas, the composition of which depends upon the ratio of air to steam, both of which are blown into the gas producer. Although this ratio can be controlled

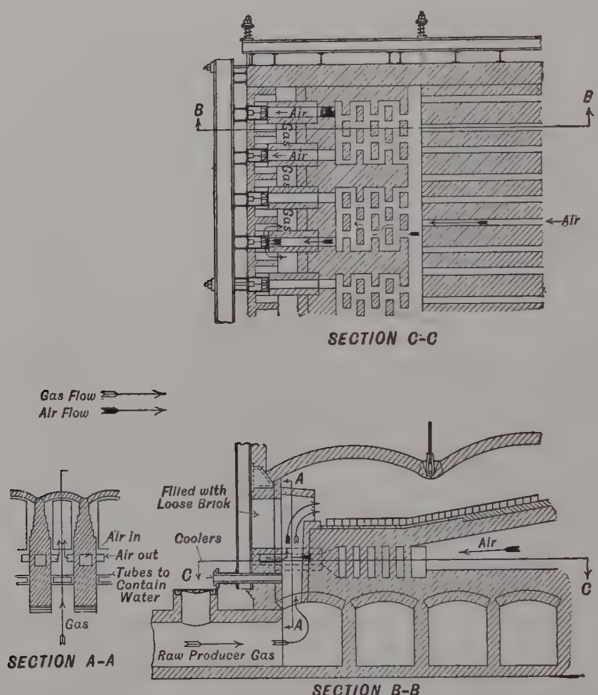


Fig. 163. Continuous furnaces for long bars. Many burners are arranged side by side. Furnace atmosphere is adjusted by the judgment of the heater.

with reasonable accuracy, control of fuel gas to air is troublesome, for various reasons. Preheated air coming from a usually leaky recuperator flows through a leaky brick duct to the burners. The heated, 30-ft-long bar travels at a snail's pace from the furnace into the first stand of the rolling mill. The rear end of the bar stays in the hottest part of the furnace longer than the front end. Overheating (which affects underfilling or overfilling of the roll passes) must be avoided. The heater holds down the temperature at the rear end of the bar by partly closing the horizontal water-cooled gate valve, one of which is located at each burner. And, since the heater has very little control over the supply and distribution of preheated air, the fuel-to-air ratio

is not constant along the length of the bar. The heater watches the bars as they come out of the furnace. The color of the bars at various points along their length tells him how to adjust the valves for the supply of heat, and the distribution of scale along the bars tells him how to adjust the valves for fuel-to-air ratio. Modern burners for raw producer gas, as illustrated by Figs. 60 and 62, reduce the difficulties, but do not altogether obviate them.

The difficulties set forth in the preceding paragraphs can be and have been overcome, if a clean fuel is burned in either cold air or preheated air. If the temperature of the preheated air can be maintained constant, independent of the rate of heat delivery to the furnace, the problem is no different from that which exists with cold combustion air, except that hot, explosive mixtures cannot be carried in pipes, on account of the greatly increased tendency to light back and explode. Constancy of temperature of preheated air (whether coming from a regenerator or a recuperator) can be had only by thermostatic control apparatus, which engineers are unwilling to specify for small and medium-sized furnaces but do commonly specify for large and important furnaces. For such furnaces the cost of control equipment, although great, is but a small fraction of the cost of the furnace, and an instrument man is usually available for maintenance. If absolutely tight metallic recuperators are employed, the metering of the air for proportioning purposes can be done before the air enters the recuperator, and preheated air offers no new problems except flashback.

Combustion Control with Solid Fuels. Maintaining a constant fuel-to-air ratio is not easy if solid fuel is being burned. The difficulty is greatest if coal is being burned on a grate. It is a well-known fact that air, passing through a fuel bed, first burns the carbon to CO_2, and that part of the CO_2 is reduced to CO in the upper layers of the bed, so that the gases leaving the fuel bed contain a considerable amount of combustible matter and produce a so-called reducing atmosphere. Adjustment of the nature of the furnace atmosphere calls for an adjustment of primary (under the grate) and secondary (above the fuel bed) air. This adjustment must vary with the size and character of the coal, with the depth of the fuel bed, and with amount of ashes and clinkers on the grate. Automatic control of furnace atmosphere is, therefore, difficult although not impossible. It should, however, be emphasized that, in the past, excellent heating has been done with solid fuel and by experienced craftsmen who love their work. A CO_2 recorder mounted near the fire door is very helpful.

Conditions are very similar with regard to stokerfired industrial fur-

naces. With stokers, a poorer grade of coal (slack, or run of mine) is usually employed. When this is used, the fuel bed frequently does not allow the passage of sufficient air for combustion of the gases given out at its top, and a considerable portion of the combustion air must be admitted through openings above the fuel bed. To make the control of furnace atmosphere in stokerfired furnaces automatic, the coal feed, the air delivery below the grate, and the delivery above the grate should be interconnected, and should be very carefully adjusted. If they are not properly adjusted, either the fuel bed will become thicker and thicker or else it will burn thinner and cause thin spots in the fire.

On account of the varying ash content and of the clinker formation, it is almost impossible to maintain the correct atmosphere automatically for any length of time. From time to time the heater must check the thickness of the fuel bed and must satisfy himself that it is still correct. Since a heater is necessary in any event and since he must frequently check the fuel bed, automatic control of furnace atmosphere, with mechanical stokers, is attempted with very few stokerfired industrial furnaces. As indicated above, it is possible to realize automatic control by means of meters for CO_2, CO, and O_2, which control air admission above the fuel bed. Automatic combustion control works well with stokers for large steam generators, but is too expensive for the average industrial furnace.

With powdered coal, accurate control of furnace atmosphere is easier than it is with coal on the grate because the flow of fuel can be measured with some degree of accuracy if fineness, moisture, and aeration of the powdered coal are kept constant. The weight of coal delivered in unit time is proportional to the speed of the feeder, whereas the weight of air delivered in the same time is proportional to the square root of the pressure difference across the measuring orifice.

Control of Prepared Atmospheres. Many engineers, metallurgists, and furnace operators, when speaking of a controlled atmosphere, mean an extraneously prepared cold gas, having a definite constant composition, and being delivered to the heating chamber of a furnace. Most of the prepared atmospheres are now formed in separate gas generators and pass through eliminators, before the resulting gases enter the heating chamber. In most of the generators a fuel gas is partly burned. *Control of furnace atmosphere, then, consists principally in keeping constant the ratio of fuel and air that enter the generator and in eliminating* H_2O *and* CO_2.

Gas generators are extraneous to furnaces in the same manner as are gas producers, coke ovens, oil refineries, oil heaters, coal pulverizers, and other auxiliary equipment. Although a description of gas gener-

TABLE XIII

No.	Composition*: Gas Constituents, % by Volume						Applications: Metal to be Treated					Comparative Cost of Unit Volume
	CO_2	CO	H_2	CH_4	H_2O	N_2	Copper	Low C Steel up to 0.20 C	Med. C Steel 0.20-0.60 C	High C Steel above 0.60	Special Steels	
1	0.0	20.7	38.7	0.8	0.0	39.8		Carburizing Dry cyaniding Homogeneous carburizing Brazing and sintering	Carburizing Bright annealing Clean hardening Carbon restoration (skin recovery) Dry cyaniding Brazing	Bright annealing Clean hardening	Clean hardening tungsten, molybdenum, and cobalt high-speed steels	$3.28
2	10.5	1.5	1.2	0.0	0.8	86.0	Bright annealing Sintering					1.00
3	5.0	10.5	12.5	0.5	0.8	70.7		Bright annealing Brazing	Up to 30 min exposure Bright annealing			1.29
4	0.05	1.5	1.2	0.0	0.0	97.25	Bright annealing	Bright annealing	Bright annealing Clean hardening	Bright annealing Clean hardening		1.42
5	0.05	0.05	3.0 to 10.0	0.0	0.0	Balance	Extra-bright annealing	Extra-bright annealing			Clean annealing stainless steel and silicon steel	1.72
6	0.0	0.0	75.0	0.0	0.0	25.0		Rapid deoxidation of surface metal Brazing Sintering			Bright annealing stainless steel and silicon steel	1.78
7	0.05 to 2.0	0.05 to 1.0	50.0 to 99.8	0.0 to 0.4	0.0 to 3.5	Balance		Rapid deoxidation of surface metal			Bright annealing of stainless steel and silicon steel	5.00

* Compositions above are based on use of natural gas as the base gas for atmosphere production.

ators does not belong in this book, the effects and the use of protective atmospheres must be discussed.

The number of protective atmospheres is very great. A very complete tabulation, listing 33 different compositions of atmospheres, may be found in *Metal Progress,* Data Sheets, August 1947, page 256 B. For practical use, a very much smaller number of gas compositions suffices. A list of typical compositions is given in Table XIII, which was abbreviated and adapted from a publication of the Surface Combustion Corporation. With the exception of number 6, the protective gases are formed by the partial combustion of natural gas, followed by more or less complete elimination of CO_2 and of H_2O. For the purpose of carburization of mild steel, a small percentage of CH_4 (methane) is added to some atmospheres. Atmosphere number 6 is dissociated ammonia. The purpose for which each of the atmospheres serves best is clearly given in the table. Concerning atmosphere number 1, it may be mentioned that dry cyaniding is synonymous with gas cyaniding and with carbo-nitriding. It means imparting carbon and nitrogen to the surface of the ferrous charge. The cost data at the right of the table are comparative only. The actual cost, for example in cents per cu ft, does not remain constant because of rise in wages.

The rate at which soft steel is carburized depends upon its initial carbon content, upon furnace temperature, and upon percentage of hydrocarbons in the atmosphere (see Fig. 153). The fact that the electrical resistance of a steel wire varies with its carbon content has been used to determine the influence of both variables. A steel wire, of a given length, with a given carbon content, and having a known electrical conductivity, is brought to a test temperature in a test atmosphere. The wire is then cooled quickly in the same atmosphere, and its resistance is measured at room temperature. This same principle can be utilized for currently measuring the carburizing effect of a protective atmosphere.[2]

For the purpose of quick carbo-nitriding, the atmosphere must contain not only a hydrocarbon gas but also ammonia. In the furnace, nitrogen that results from the cracking of ammonia is atomic and, for that reason, is ready and eager to combine with iron.

Utilization of Protective Atmospheres. An early example of the use of a protective atmosphere is the Certain Curtain (trade name) furnace, which was introduced about 1927, and which is schematically illustrated in Fig. 164. Fuel gas, such as natural gas or manufactured

[2] A short time before the manuscript was delivered to the publisher, a paper on "Automatic Carbon Control" by Ipsen and Rufert appeared in *Metal Progress,* July 1, 1954, page. 98.

gas, is burned with a great deficiency of air in precombustion chamber *A*. The manometers *B* indicate the fuel-to-air ratio. The partly burned gas enters the heating chamber through a slot near the door, forming curtain *C*. Whenever the door is opened, the supply of partly burned gas is automatically increased. The furnace was intended to protect the work *D* against oxidation at a temperature of 2200° F, or even slightly above this value. The ratios H_2/H_2O and CO/CO_2 must be such that their intersection in Fig. 151 lies in the *R* (reduction)

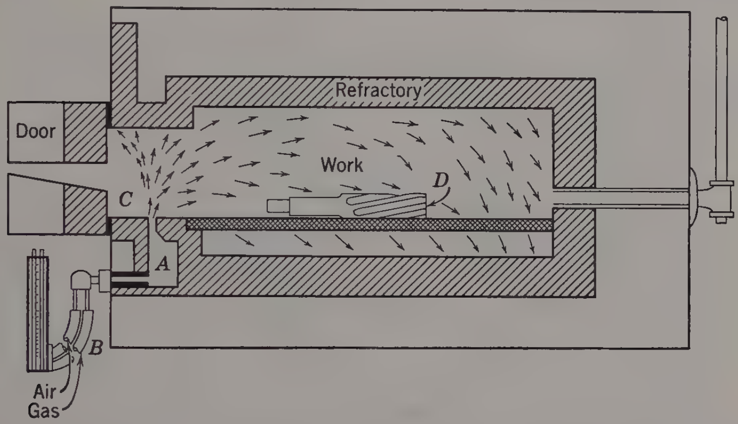


FIG. 164. Electrically heated furnace with hot protective atmosphere that is generated in furnace.

zone. To that end the air-to-fuel ratio is reduced as far as possible without extinguishing the flame and without the depositing of soot. High-temperature heat was imparted to the furnace interior by electrically heated resistors of silicon carbide.

It is impractical (and almost impossible) to heat a furnace up to 2200° F solely by the heat that is released in incomplete combustion. From Figs. 1 to 10 it can be seen that a deficiency of air lowers flame temperature and that a given depression of temperature is caused by different deficiencies for different fuels. Although the temperature that results from very incomplete combustion lies between 2200° F and 2900° F, the small temperature potential that is available for heating to 2200° F results in an excessive fuel consumption and in slow heating, which, in turn, requires an inconveniently large and expensive furnace. The heat from electric resistors increases the furnace temperature to the desired value and assigns to the hot protective gas the task of protection only and not of heating. Only enough gas is produced to maintain furnace pressure.

The resistors are not shown in Fig. 164. They are clearly shown in Fig. 165, which is a modern version of the original idea. The illustration is so well marked that no comment is needed.

Other inventors and engineers reasoned that the installation of electric resistors might be avoided if the potential heat in the furnace gases could in some way be returned to the heating chamber. In 1931,

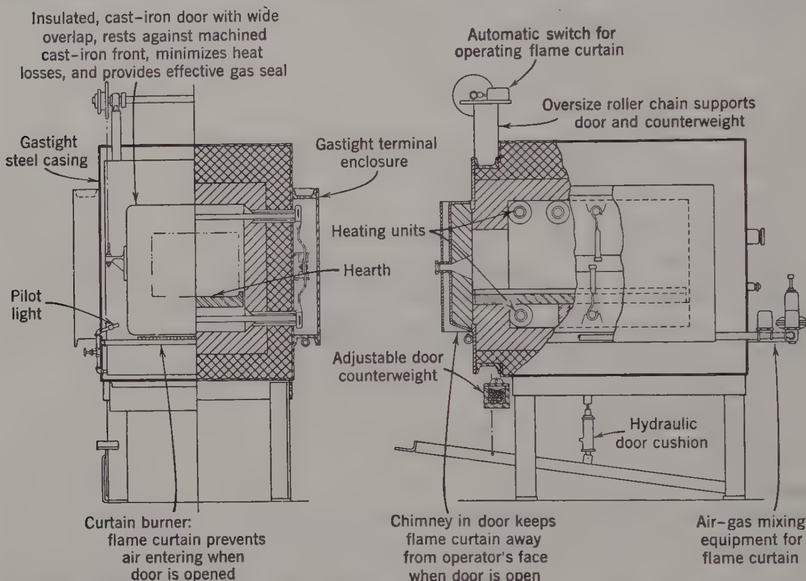


FIG. 165. Modern electrically heated furnace with hot protective atmosphere that is generated in furnace. Courtesy of General Electric Co.

the author saw a very imperfect embodiment of this idea in Witkowitz (Moravia). The furnace, which had been in operation for a few years, was regenerative. Fuel was burned in an insufficient volume of extremely hot air. At the entrance to the regenerator, sufficient secondary air was added to complete the combustion. In this scheme, the air temperature is limited by the refractoriness of the bricks in the regenerators. Accuracy of composition of furnace gases could not be maintained because of the reversals and because regenerators are leaky structures. The regenerative method of producing a directly usable, hot protective atmosphere did not take root.

A more modern and successful (recuperative) method is based on the following principle: The protective hot gas coming from the heating chamber is completely burned in an adjacent chamber, from which heat is transmitted to the heating chamber. This principle is illus-

trated by Fig. 166, which is purely schematic without any attention to structural details. *A* is a very hot chamber. It transmits heat to silicon carbide tubes *B*, in which fuel burns with a deficiency of air. The flame temperature is boosted by heat flowing from space *A* into tubes *B*. The hot products of incomplete combustion give up part of their heat to the charge in the heating chamber *C*, from which they flow into chamber *A*. On their way, they are mixed with preheated air and are burned at a high-temperature level. From chamber *A*,

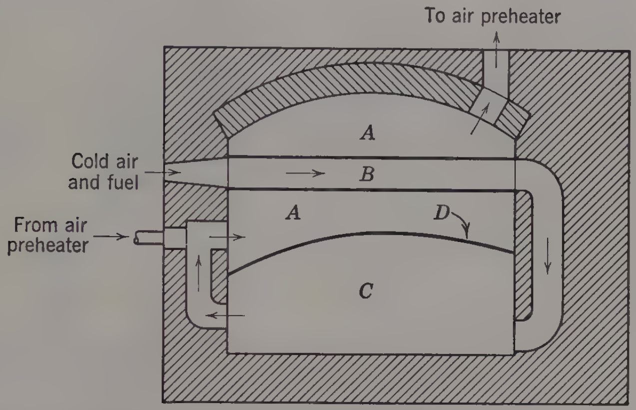


FIG. 166. Schematic illustration of furnace in which a hot protective atmosphere is generated without external heat.

the hot gases pass into an air preheater (recuperator), which is not shown in Fig. 166. In addition to transmitting heat to tubes *B*, chamber *A* also transmits heat to silicon carbide arch *D*, which radiates heat into chamber *C*. Composition of the hot protective atmosphere can be accurately controlled.

Furnaces that embody the principle of Fig. 166 have successfully heated steel to temperatures as high as 2350° F, without any scale formation whatsoever. Depending upon the use, such furnaces are built in different types. Fig. 167 is a drawing of one of these furnaces, as actually built. Before adopting the principle of Fig. 166, the builders of the furnace of Fig. 167 endeavored to prevent scale formation by introducing vapors into the heating chamber, where the vapors condensed on the cold charge and formed a protective coating. The salts that were evaporated consisted mainly of lithium carbonate and of lithium chloride.

These salts lay in a container, named a "lithium boat." The container rested in one or more separately fired evaporators attached to

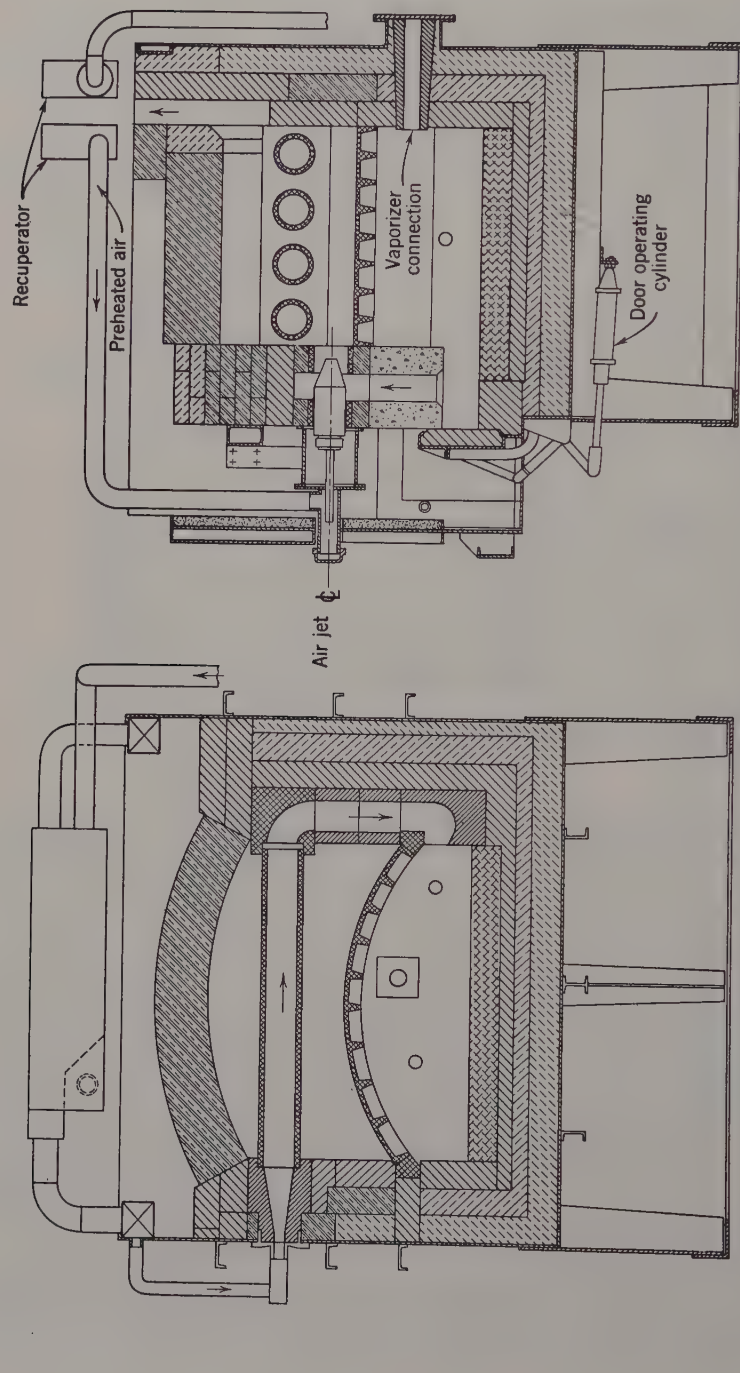


Fig. 167. Triple recuperative furnace for scale-free heating up to 2300 F. The furnace generates a hot, protective atmosphere without external heat. (Courtesy of The Lithium Co.)

the furnace. The arrows in Fig. 168 indicate how the hot products of combustion from the auxiliary burner pass over the lithium boat and carry its vapor into the heating chamber. Furnaces built on the principle of Fig. 166 positively prevent scale formation while the charge is in the furnace. Scale can be prevented while the hot material is on its way to the processing equipment or while it is being processed if lithium salts are employed in the furnace. The lithium coating is also a good lubricant for the dies of hammers and presses, including extrusion presses.

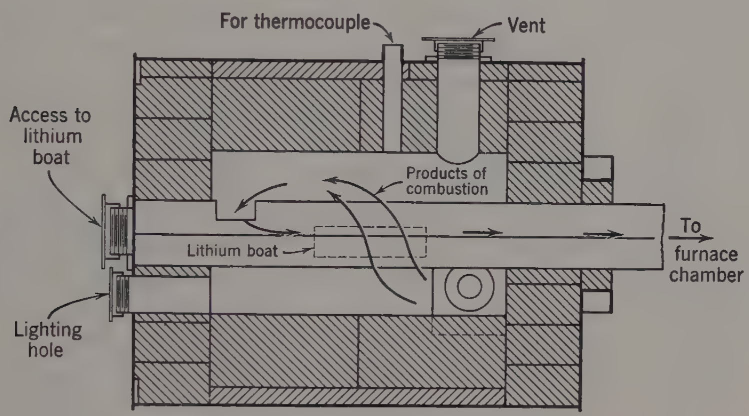


FIG. 168. Vaporizer for lithium salts.

The atmosphere in furnaces of the type that are illustrated by Figs. 166 and 167 can be used not only for scale-free heating but also for reducing previously formed scale and for recarburizing steel. The furnace under discussion is an improvement over furnaces into which cold, separately prepared atmospheres are introduced. So far as the author knows, the furnace illustrated in Figs. 166 and 167 is the only type in which the furnace generates its own protective atmosphere, and then, by secondary combustion, utilizes the protective gas for heating the charge up to any temperature that is required in metal-heating furnaces.

By far the greatest number of "atmosphere" furnaces are now served by detached gas generators. So far as the author has been able to ascertain, the detached gas generator was invented in Attleboro, Massachusetts, about 1930. The following statements refer to the combination of furnace and generator of atmosphere gas: A separate gas generator requires an additional investment. It requires auxiliaries for various purposes; it requires expenditure for the fuel from which the atmosphere is made and for cooling water to almost eliminate

moisture; it requires heat for bringing the cooled gas up to temperature in the furnace; and it requires electric power. Some atmospheres require external heat in their preparation; still others require refrigeration and a chemical process for the elimination of carbon dioxide. For all of these reasons, atmosphere gas is used with economy; it is husbanded.

The need for furnace pressure is as great in atmosphere furnaces as it is in other furnaces. For that reason, and also because atmosphere gas is both expensive and toxic, atmosphere furnaces must be built tight and must be kept tight. They are usually inclosed in welded steel shells or casings. Doors are pressed against their seats by springs or by gravity (inclined doors). In order to reduce the escape of atmosphere gas, furnaces are equipped with vestibules whenever possible. The charge is pushed or otherwise transported into the vestibule while the furnace door is closed. After the vestibule door has been closed, the furnace door is opened and the charge is transported into the furnace. The vestibule-furnace door is then closed and the charge is exposed to heat. The vestibule and the doors are clearly shown in Fig. 169, which is an idealized perspective view of a "general purpose" atmosphere furnace. The charge resting on a tray is pushed into the heating chamber by a rod and is later on pulled out by similar means. The furnace is heated by metallic resistors, and an airtight quenching tank lies under the vestibule. In spite of this precaution (the vestibule), leakage cannot be entirely avoided, and some generator gas must be flowed through the heating chamber while the furnace is in operation. Many continuous furnaces have doors at each end. The leakage is correspondingly greater. In furnaces of the bell and hood type, such as are used for the annealing of flat sheets and coiled strip, the whole charge of protective gas is lost at the end of the heat.

If the charge is moved continuously, for instance on a link chain or on a woven chain, a vestibule with tightly fitting doors cannot be installed. Instead, light chains or wire screens, or both, hanging from the roof of the vestibule reduce the inflow of air and the outflow of protective gas. A furnace without vestibules is illustrated by Fig. 170. In this furnace long bars or tubes can be bright annealed. Length and diameter of the pieces vary from time to time. Twenty-five wire screens at each end are intended to approach the action of vestibules. The wire screens are flexible and adjust themselves to the shape of the charge. They not only offer resistance to the flow of gases, but they also act as radiation screens. Each door is equipped with a flame curtain, which prevents the inflow of air when the door is open. Radia-

tion screens are also arranged between heating zone and cooling zone. Other furnaces of the same type are equipped with alloy fans, not only in the cooling zone but also in the heating zone. The furnace illustrated in Fig. 170 has an overall length of almost 111 ft.

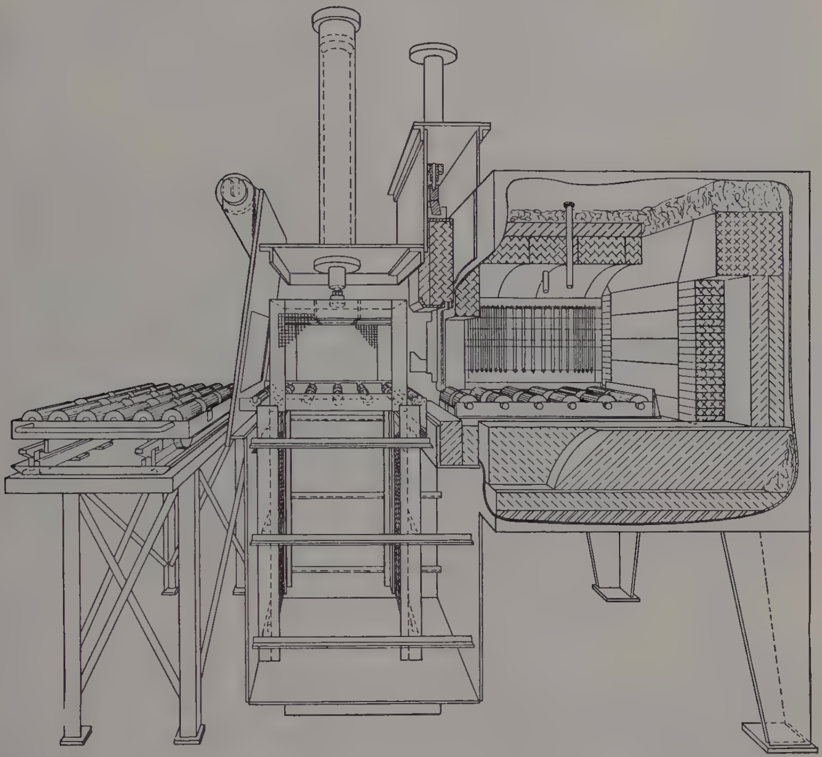


Fig. 169. "General purpose" batch-type furnace filled with protective atmosphere. Courtesy of Westinghouse Electric Co.

Atmosphere furnaces must be tight not only externally but also internally, which means that raw products of combustion must not enter the heating chamber. This requirement is easily met in electrically heated furnaces up to roughly 1900 F. Those metallic resistors that withstand temperatures up to 2300 F in oxidizing atmospheres cannot be used in reducing atmospheres (see Chapter II). Resistors of silicon carbide do well in high temperatures, although the life of these resistors is shortened by hydrogen.

The entrance of raw products of combustion into the heating chamber is prevented by muffles. Heating the charge inside a muffle is practiced mainly in furnaces of the hood type or bell type in which sheets

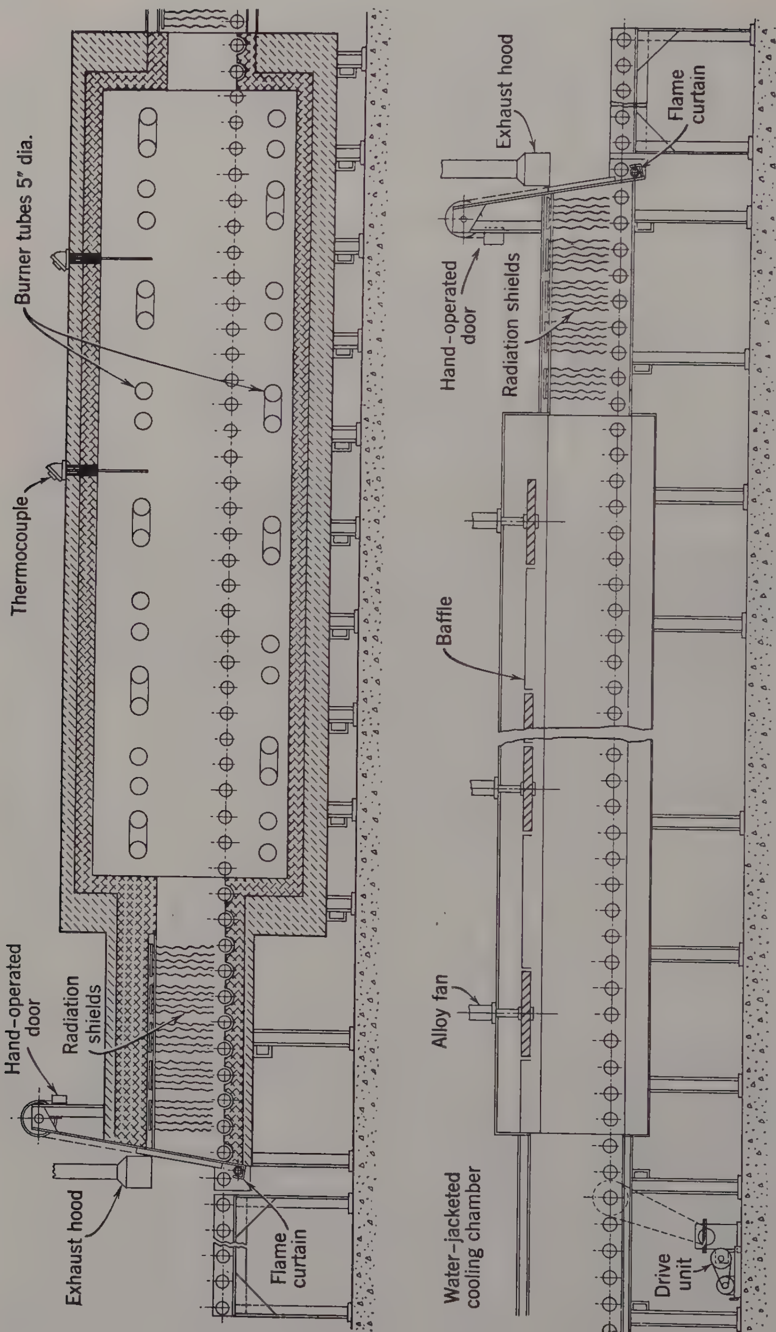


FIG. 170. Continuous "atmosphere" furnace without vestibules. Courtesy of Westinghouse Electric Co.

and strips are heated. Surrounding the charge by a muffle is also practiced for heating other objects, but less frequently. When coal serves as fuel, muffles are even now used in ceramic furnaces for the purpose of keeping soot, flyash, and sulphur away from the charge.

The invention of radiant tubes placed the flame, and not the charge, into the muffle. In the beginning radiant tubes were vertical. They are now used either vertically or horizontally; if horizontal, they are often of the hairpin type as shown in Fig. 171. Radiant tubes are

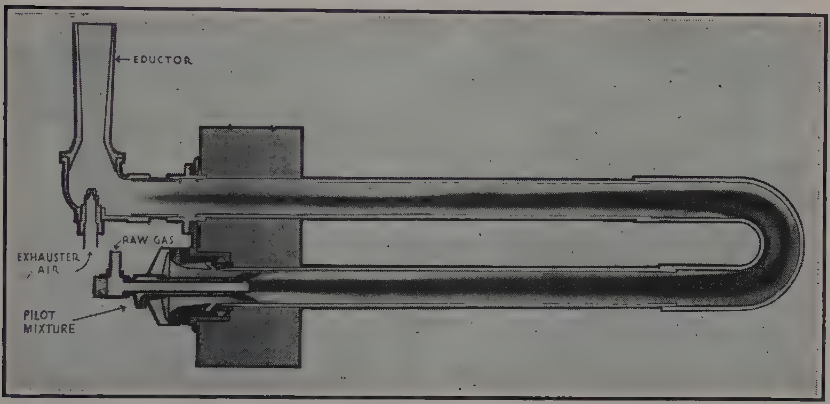


FIG. 171. Radiant tube of the hairpin type. Courtesy of Surface Combustion Corp.

made of high-alloy steel. The temperature of the interior of the tube exceeds furnace temperature. The dark streak in the tube represents the artist's idea of the progress of combustion. The burner is designed for slow combustion to prevent local overheating and rapid destruction of the tube. An exhauster maintains a slight vacuum in the tube to prevent the entrance of raw products of combustion into the heating chamber, if the tube burns out in one or more spots. The illustration is idealized. Actually the eductor does not lie in the plane of the drawing. If it did, it would interfere with the next tube, no matter whether the tubes lie in a vertical wall or in a horizontal wall. Hairpin tubes equalize temperature to some extent, but not altogether. For better equalization, tubes are fired alternately from opposing walls. If the tubes have to be very long, they are equipped with extensions at the extreme ends of the return bends. The extensions rest on the opposite wall in such a manner that expansion can occur freely. In Fig. 170, already referred to, hairpin tubes are shown in cross section above and below the charge. Between the rows of tubes are rollers.

The dead end of each roller is sealed; the live end is packed tightly. Almost all radiant tubes are fired by gas. Oil causes some difficulties.

Some very cautious engineers have combined radiant tubes with muffles around the charge.

Radiant tubes are successfully used in atmosphere furnaces up to the highest temperatures that occur in industrial furnaces, if the tubes are made of silicon carbide. This material is a refractory and cannot be made in hairpin shape, at least not at the present time. The length of the tubes is also limited. Fig. 172 shows how the length of the

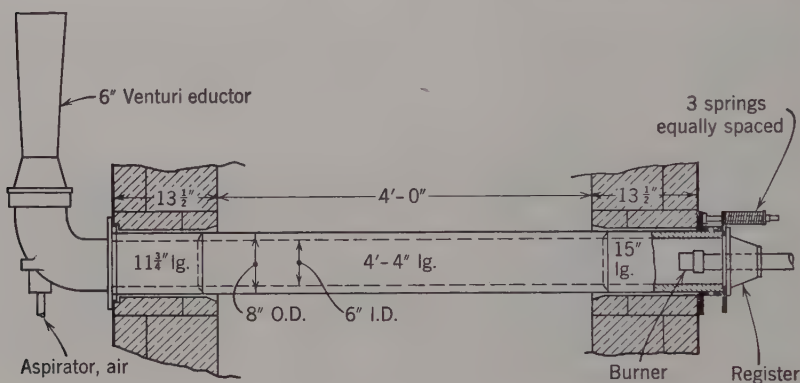


Fig. 172. Radiant tube of silicon carbide. Courtesy of Gas Machinery Co.

tube is artificially increased and how expansion is provided for. The length of the main tube is 4 ft, 4 in. At each end of the main tube is a shorter tube that fits against the main tube with spherical joints that are kept reasonably tight by two factors: The joints are filled with a cement that has a silicon carbide base, and are pressed against each other by springs, which also take care of unequal expansion.

The control of prepared atmospheres varies with the nature of the atmosphere. Control is simple if there is no atmosphere. This statement refers to annealing metals in vacuum. A pot furnace for annealing in vacuo is shown in Fig. 173. The pot is heated by electric resistors. The charge must remain in the pot until it has been cooled below the temperature of scale formation. This takes time. Annealing in vacuo is not suited to mass production.

The composition of atmospheres that are derived from incomplete combustion of fuel is controlled in the manner that is used for combustion control. The ratio of air to fuel is decided upon and is then maintained by one of the methods described earlier in this chapter (under Combustion Control). Incomplete combustion in the gas gen-

erator is followed by cooling and, if required, by absorption of carbon dioxide. If carburization and nitriding are required, methane and ammonia are added, measured in a similar manner. If the protective gas is to be rich in hydrogen and carbon monoxide, external heat must be imparted to the reaction chamber of the gas generator.

Separate gas generators are auxiliaries that, in turn, have other auxiliaries. Their theory and design do not belong in a book on industrial furnaces.

It should be mentioned that carburizing atmospheres can be produced by the time-honored method of pack hardening. The charge is packed in charcoal and in leather cuttings; the latter contain some nitrogen. The container is deposited in a furnace and is heated. The life of the container is short, and the labor cost is high. Pack hardening is still practiced for occasional hardening in small jobbing shops.

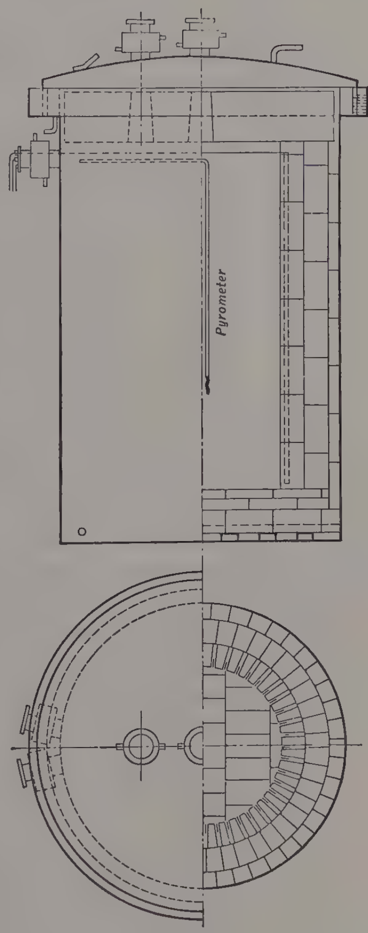


FIG. 173. Electrically heated bright-annealing furnace of the pit type, designed for complete evacuation.

Control of Atmosphere in Lead Baths and in Salt Baths. Although this subtitle may look absurd, it is nevertheless descriptive.

Lead has no affinity for steel or for copper or for many other metals. Immersion of pieces made of these materials does not affect the lead. The latter remains as pure as it was originally. An oxide skin forms on the surface of the hot lead bath. The oxide is skimmed off from time to time.

Matters are more complicated in the use of salt baths, because a difference exists between salts that are used solely for heating and other salts that serve not only for heating, but also for carburizing and for nitriding. Another difference is caused by the temperatures at which different salts melt and by the temperature ranges within which

TABLE XIV

NOMINAL COMPOSITIONS OF SALTS

Type	Percentage Compounds by Weight										Approximate Melting Point, F°	Recommended Heating Range, F°
	$NaCl$	KCl	$BaCl_2$	$NaNO_3$	$NaNO_2$	KNO_3	$CaCl_2$	$NaCN$	Na_2CO_3	KCN		
L1	—	—	—	*	40/50	50/60*	—	—	—	—	290	325/1200
L2	—	—	—	40/50	—	50/60	—	—	—	—	440	500/1200†
L3	—	—	—	96 min.	—	—	—	—	—	—	700	750/1200†
L4	30/40*	*	—	—	—	—	—	15/40	30/50	—	1020	1150/1500
L5	15/25	—	25/35	—	—	—	45/55‡	—	—	—	900	950/1400
I1	45/55	45/55	—	—	—	—	—	—	—	—	1250	1350/1650
I2	15/25	20/30	50/60	—	—	—	—	—	—	—	1100	1250/1700
I3	20/30	—	70/80	—	—	—	—	—	—	—	1300	1400/1700
I4	10/20	—	80/90	—	—	—	—	—	—	—	1400	1500/2000
H1	—	—	98 min.	—	—	—	—	—	—	—	1800	1900/2450
H2	4/8	—	92/96	—	—	—	—	—	—	—	1600	1750/2300
C1	4 max.	—	—	—	—	—	—	96 min.	4 max.	—	1150	1450/1750
C2	*	—	—	—	—	—	—	—	4 max.*	96 min.	1150	1450/1750
C3	*	5/10*	40/50	—	—	—	—	35/40	—	—	1150	1550/1750
C4	15/25	—	—	—	—	—	—	45/50	20/30	($BaCO_3$)	1150	1500/1750
C5	20/30	—	15/25	—	—	—	—	30/40	20/30	—	1150	1450/1650
C6	10/15	—	—	—	—	—	—	70/80	10/15	—	1150	1500/1750
C7	15/25	—	—	—	—	—	—	60/70	15/25	—	1150	1500/1750
C8	40/50	—	—	—	—	—	—	40/50	5/10	—	1150	1500/1750
C9	—	60/70*	—	—	—	—	—	30/40	*	—	925	975/1200
C10	—	—	—	—	—	—	—	55/65	—	35/45	925	975/1200

* Either of the two materials marked by an asterisk in this line, or any mixture of the two materials, may appear in the percentage shown under the one material.

† The materials should not be operated above 1100 F in a fuel-heated pot.

‡ This material is hygroscopic and should be added to molten salt with great care.

they can be used. The important properties of commercially used salts are given in Table XIV, which was taken from *Steel Processing,* March 1953. It appeared originally in "The Metals Handbook," 1948 edition, page 284. The letters in the first vertical column refer to the temperature range, somewhat arbitrarily. *L* stands for low, *I* means intermediate, *H* stands for high, and *C* stands for carburizing. Obviously a salt mixture must be selected for the temperature range in which it is to be used. A charge that is to be heated to 1400 F cannot be immersed in a salt that is still solid at that temperature. It is also clear that a charge which is to be heated to 2200 F should not be immersed in a low-temperature salt, because that salt would break down and partly evaporate if heated to 2200 F. Furthermore, the melting temperature of the salt should lie at least 150 F below its operating temperature. This difference of temperature apparently produces most rapid heating without excessive thermal shock.

Salt baths, with the exception of borax, absorb oxygen from the atmosphere and pass the oxygen on to the charge. A small amount of borax, about 2 per cent, reduces this action. Additions of ferrosilicon or of sodium nitrate have a similar effect. Oxidation is also prevented by a layer of flake graphite on the surface of the bath.

The cyanide baths are intended to change their composition by giving up cyanogen (C_2N_2) to the charge. In consequence, fresh cyanide salts must be added from time to time. So far as the author knows, control of composition of salt baths is not yet automatic. A sample of the bath is analyzed, and fresh salt is added to restore the correct composition. Another reason exists for adding fresh salt, namely, the dragout. Salt sticks to the leaving, heated charge; the salt must be replaced.

CHAPTER V

LABOR-SAVING APPLIANCES

Classification of Labor-Saving Devices. In the cost of industrial heating, the item of labor occupies a major position. Comparatively speaking, fuel is cheap and labor is expensive. Although this statement may not be true in other countries, it certainly holds in the United States; it is, therefore, only natural that many labor-saving devices should have been introduced in this country in connection with furnace work. The following statement, which was made by a prominent furnace engineer, is significant: "In our advertisements we stress fuel economy, but we sell our furnaces on labor-saving features." Labor-saving devices used with furnaces fall roughly into three groups.

One group of devices serves for saving labor in the generation and application of heat. The appliances of this group may be subdivided into (*a*) those which automatically deliver fuel to and into the furnace and (*b*) those which automatically maintain constant temperature and atmosphere in the furnace. A second group consists of those materials and designs which reduce furnace maintenance and repairs; whereas a third group embraces those appliances which reduce the labor of charging, transporting, and discharging the material to be heated.

The characteristic features of the first-named group, the devices used for saving labor in the generation and application of heat, are briefly described in Chapter I, Fuels, and in Chapter II, Combustion Devices. Additional information on this topic is contained in Chapter VI. The second group of labor-saving equipment is intended to increase the strength and durability of furnaces, both of which are discussed in Volume I. It is the third group, namely, labor-saving devices used in connection with the charging, transporting, and discharging of the material to be heated, which forms the topic of the present chapter. A subdivision of the third group consists of that equipment which, although not strictly labor saving, is closely allied with the equipment under discussion, as it serves to make work around furnaces comfortable and increases the work done per man in unit time.

Devices for saving labor in the handling of materials form two broad classes, depending very largely upon the type of furnace which

they serve. One class is used for charging and emptying batch-type furnaces, whereas the second class consists of equipment for delivering the stock to a continuous furnace and for moving it through the furnace.

Labor-Saving Equipment for Batch-Type Furnaces. The devices for moving material into and out of batch-type furnaces cover a wide range. They include simple containers, such as pots, pans, and trays, as well as special cranes and complicated charging machines.

Pans and trays for containing piled material are in very common use not only for very small articles but also for pieces as large as couplers for railroad cars. A typical pan has been sketched in Fig. 174. It will be noted that it has short legs, which serve two purposes: first, they allow the fork of the lifting lever or charging machine to enter between the hearth and the tray itself; second, they elevate the charge above the floor and allow circulation of the furnace gases under the tray. Not all trays need legs for handling because some furnace hearths have grooves, into which the prongs of the charging device slip. Rails that project from the hearth serve the same purpose.

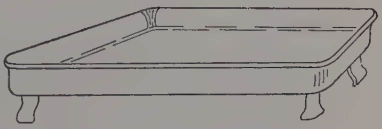


Fig. 174. Tray container.

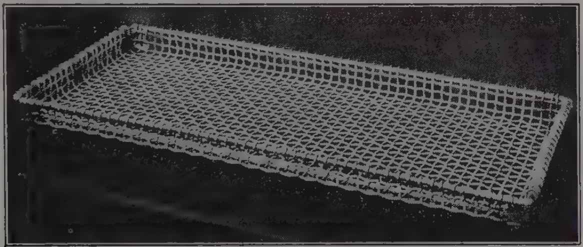


Fig. 175. Wire-mesh tray.

It is evident that any heat which was imparted to the tray is lost unless the tray can be dumped and immediately charged again before it has become cold. Since this method is very seldom applicable, the heat in the tray is, as a rule, lost. For that reason trays are made just as light as is consistent with strength and rigidity. Some trays are made of special wire mesh, as shown by Fig. 175. Trays of this general type are useful in connection with batch furnaces, such as illustrated by Fig. 169. Being supported by rollers at all times, even in the quench, they can be made light. The trays are made of heat-

and corrosion-resisting alloys. Some trays are heated in products of combustion; others are exposed to cyaniding atmospheres, gaseous or liquid; many are quenched.

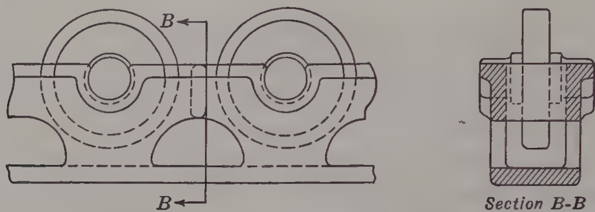


FIG. 176. Alloy roller rail, conventional type.

Trays that are pushed through long furnaces must be strong enough to overcome the friction of the whole line of trays. For such service, wire-mesh trays are out of place. The force required for pushing is reduced by moving the trays on roller rails, one of which is shown

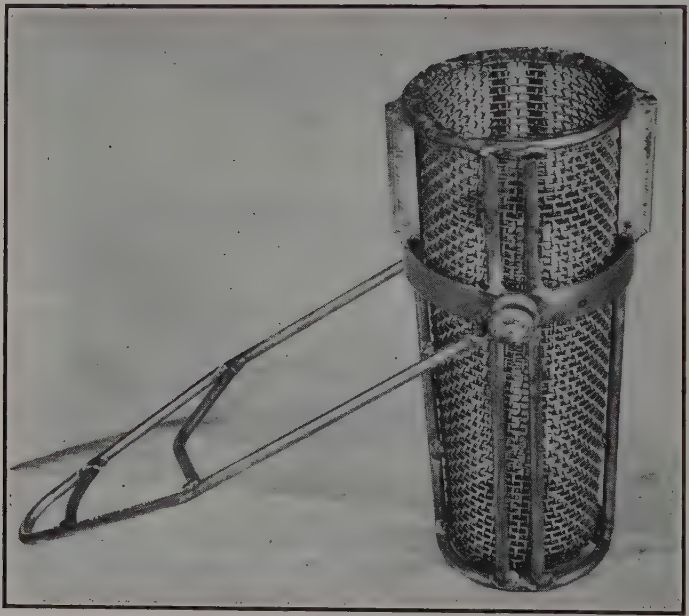


FIG. 177. Salt-pot basket. Courtesy of Rolock, Inc.

in Fig. 176. The smaller the journal in comparison to the diameter of the roller, the more the friction is reduced. Bearing pressure and furnace temperature set a limit. It is advisable to consult the makers of roller rails with regard to carrying capacity at elevated tempera-

tures. Friction is reduced and carrying capacity is increased, if the under side of each tray is coated with graphite. In the furnace most of the graphite drops off and lubricates the bearings of the roller rails.

In salt-bath furnaces, trays became baskets and buckets of an indescribably great variety. Only a few typical containers can be illustrated here. Fig. 177 represents a basket in which small parts

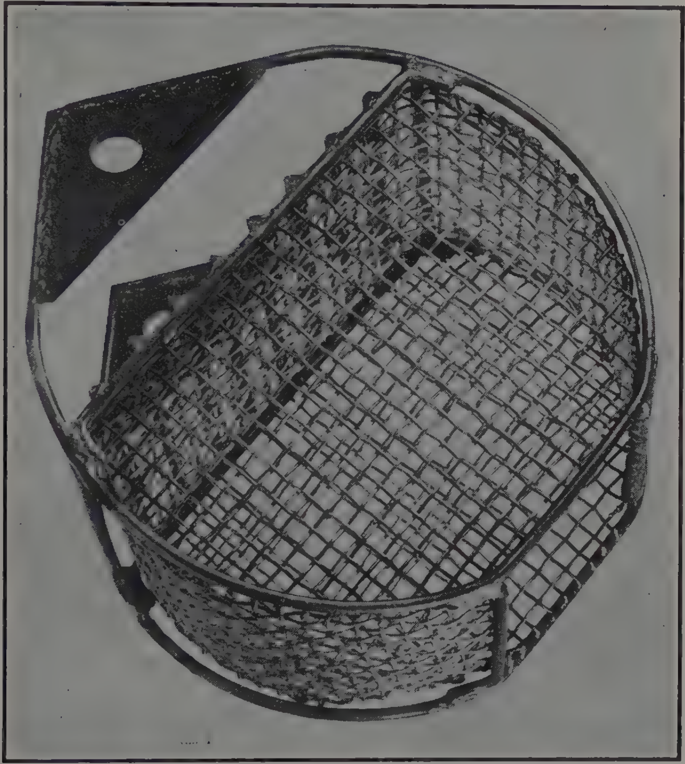


Fig. 178. Lead-bath basket. Courtesy of Rolock, Inc.

are carburized for quenching. The two-pronged swing handle and the tapering sides of the basket facilitate a quick dumping of the charge. Baskets that are to be immersed in lead baths must have a top cover and must be rigidly supported so that they cannot tilt upward. Fig. 178 illustrates both features. The charge is inserted from the side. While in the lead bath, the charge floats against the top of the container. A vertical rod or bar passing through the holes (at the left in the picture) allows the basket to turn in a horizontal plane, but prevents upward tilting.

Repeated heating and quenching disintegrates baskets and other containers. For that reason, containers are often equipped with drop bottoms (also called dump bottoms), which are made of wire netting,

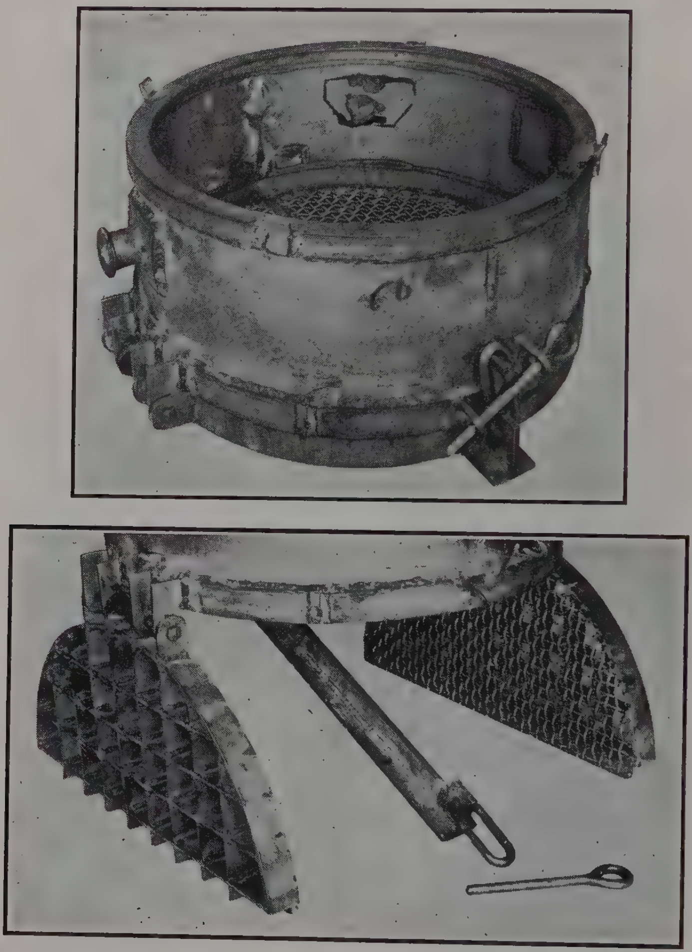


FIG. 179. Dump-bottom basket. Upper part: bottom closed; lower part: bottom open. Courtesy of Rolock, Inc.

for the purpose of facilitating circulation through the charge in the heating bath. Small buckets are equipped with undivided mesh bottoms that are hinged on one side only. Buckets of large diameter are equipped with split bottoms. An undivided bottom of large diameter requires a high lift; when the bottom is opened, the charge slides to one side. The divided or split bottom overcomes these troubles. A

container with split bottom is illustrated by Fig. 179. In the upper portion of the illustration the bottom is shown closed; in the lower portion of the picture, the bottom is shown opened up. The device for holding the bottom shut, while the container is in the bath, is clearly shown in both parts of the illustration.

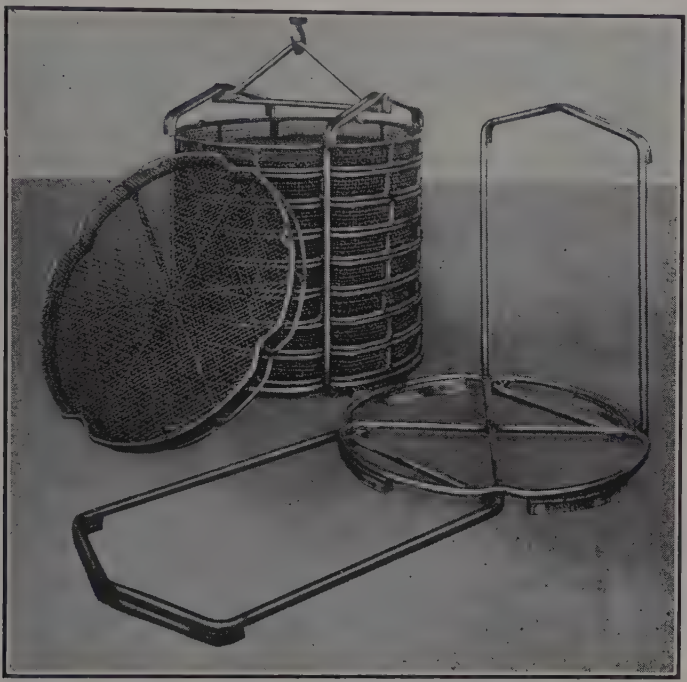


Fig. 180. Stacked trays for salt bath. Courtesy of Rolock, Inc.

Trays for small objects are often stacked; an example is pictured in Fig. 180. This particular set of trays serves for heat-treating permanent magnets. The device for locking the individual trays together and for transporting them is clearly shown.

Pans, pots, or trays are usually moved in and out of the furnace by means of lifting forks, equipped with wheels. A sketch of such a lifting fork is given in Fig. 181. Many modifications of the lifting fork are in common use; they depend upon the size, height, and design of the furnace and upon the shape of the container to be lifted. If the furnace hearth is near the floor of the building, the handle of the lifting fork is bent upward. If the hearth is elevated, the handle of the fork has the shape shown in Fig. 181. In that case, the wheels rest on a table which is rolled up to the furnace door.

If the furnace is of small depth (measured horizontally, at right angles to one of the doors), small containers or individual pieces are often handled by a double-armed lever; the charge is carried at the end of the short arm, while the operator handles the end of the long arm. The pivot of the lever is suspended from a wheel truck that travels on an overhead monorail. This handling device is more fully described in the section on furnaces with rotating hearths.

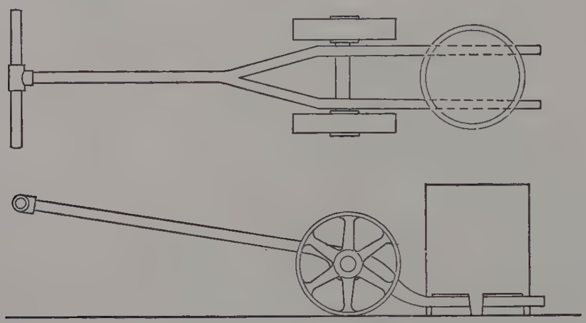


FIG. 181. Wheeled lifting fork.

For medium-sized furnaces with hearths above the floor level a Swiss device is of interest; it is shown in Fig. 182. The crane puts the device down in front of the furnace and sets the container on it. It then lifts the container carrier, after which the attendant rolls the container into the furnace and sets it down on the rails. Numerous modifications are possible.

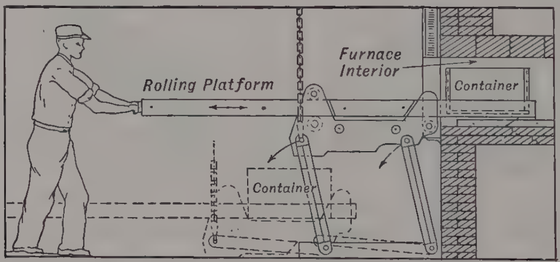


FIG. 182. Crane-operated furnace charger.

When individual pieces, not resting in a container, are heated in a furnace, the handling is done with tongs if the individual pieces do not weigh more than 40 or 50 lb. Heavier bars or pieces to 400 or 500 lb are handled with tongs or with peels which are suspended from a mono-

rail. Still heavier blooms, slabs, or forgings are handled by tongs suspended from cranes, or else are handled by means of manipulators or charging machines. Heavy bars or forging ingots are frequently handled by means of porter bars which are suspended from cranes, as illustrated in Fig. 183. Heavy ingots, hanging from porter bars, must be handled very slowly and with extreme care because the sudden stopping of a crane which carries a fast-moving ingot at the end of a porter bar produces a long, forward swing. Altogether too often the ingot strikes the furnace walls or the door jambs, or else the chain

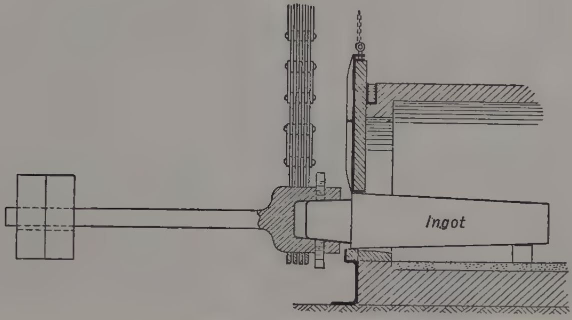


FIG. 183. Porter bar suspended from crane.

strikes the top of the door, and the bricklayers are kept busy. In some forge shops the repair bills have been reduced by the installation of projecting aprons just above the furnace doors. Although these aprons save the furnace, they are disliked by the heaters because they do not allow the crane chains to come close to the furnace door.

The porter bar shown in Fig. 183 often remains attached to the ingot while the ingot is in the furnace. With this arrangement, part of the ingot projects out of the furnace. If the whole ingot or heavy bloom is to be placed inside of the furnace, it is necessary to attach the porter bar to the bloom by means of tongs. A design serving this purpose is shown in Fig. 184. It is readily observed that this clamping device is a toggle-joint mechanism, which is based on axial relative motion. Each clamping head is useful for only a limited range of billet sizes.

In depositing ingots in a furnace, furnace tenders often place a roller at the end of a handle bar (compare Fig. 185) under the ingot. The crane trolley is run to a position vertically above the furnace. By this motion, the crane chain, which supports the outer end of the ingot, becomes inclined and exerts a pull toward the furnace. In consequence, the ingot, rolling over (and with) the roller, slips into

the furnace and is deposited with its rear end resting on a ledge in the furnace. The crane then lifts the front end of the ingot, and the roller is withdrawn. Reference has already been made to the fact that any heavy mass suspended from a crane is hard to handle on account of the swinging. For that reason manipulators and charging machines are very much better, although of course they are to be classed as special equipment and require an extra investment.

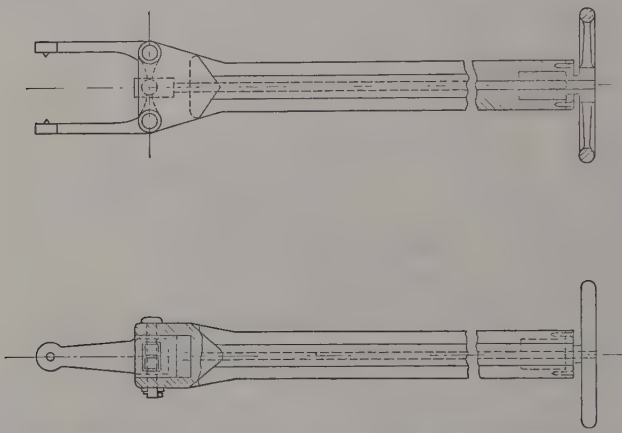


FIG. 184. Tong-hold porter bar. Turning of the handwheel attaches the bar to the bloom or disengages it.

A simple furnace charger of the get-underneath-and-lift-up type is shown pictorially in Fig. 186. Open space under the furnace permits the front extension to roll in under the furnace. Wheels directly under the load result in a charging machine that is much lighter than a machine with all wheels outside of the furnace floorspace.

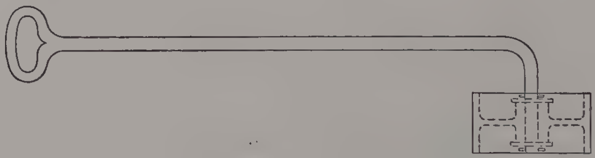


FIG. 185. Roller for shoving blooms into the furnace.

Charging machines for heavy billets were for many years built to travel on rails. The furnaces and the forging press then had to be arranged to suit the straight-line travel of the rail-bound machine. Overhead supply of electric power often interfered with crane service. A number of such machines are still in use, but more recent charging

machines move on floor plates. In several works, these machines serve not only the heating furnaces, but also the forging press. Fur-

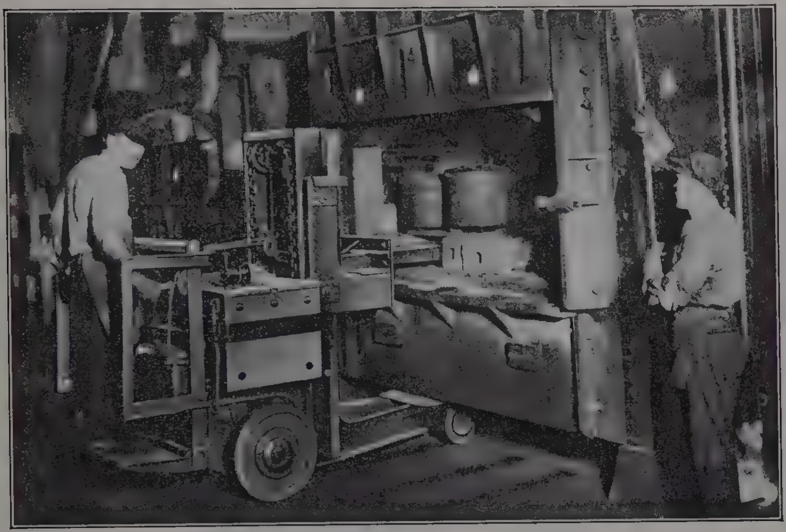


FIG. 186. Electrically operated charging machine.

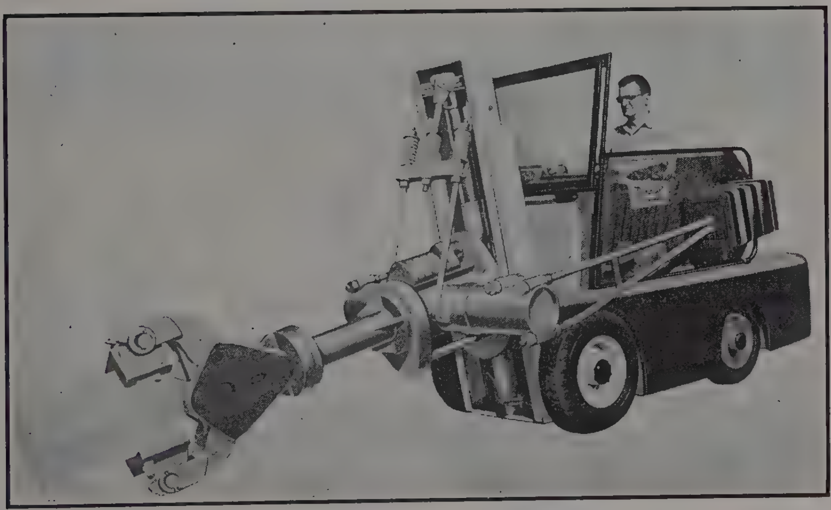


FIG. 187. Furnace charger. Courtesy of Salem-Brosius.

nace chargers of the manipulator type are illustrated in Figs. 187 and 188. The former shows a machine in the shop of the builder; at the right, one set of counterweights can be seen. The second illustration

depicts a similar machine in the act of removing a hot billet from the furnace. In a shop with good ventilation, charging machines may be operated by gasoline engines. In general, operation by electric motors is preferred. In that case, a cable with two wires is plugged into a ceiling outlet. The cable is kept taut by a spring-loaded reel which is located either under the ceiling or on the charging machine. The movement of the manipulator is universal. The machine itself is an

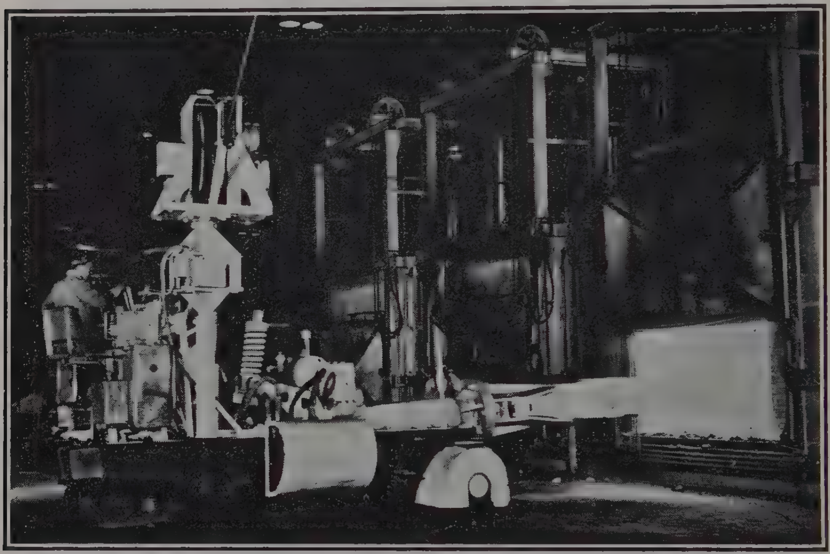


FIG. 188. Furnace charger and manipulator. Courtesy of Salem-Brosius.

automobile; the gripping device tilts, swings, rotates, and travels up and down. Scale that drops off the handled material collects on the floorplate and assists materially in wearing the rubber tires. However, this disadvantage is small when compared to the many advantages that accompany the universal mobility of the machine. Some of these charging machines have reached enormous proportions, for instance those machines that serve furnaces and forging presses for the production of demolition-bomb bodies that weigh more than 1500 pounds.

A machine (for charging and unloading) that was designed for furnaces with rotating hearths is illustrated in Fig. 189. Whereas other machines grip laterally, this machine grips the billet longitudinally, acting like a huge monkey wrench. The hydraulic hose that transmits the pressure for clamping is not shown in the illustration. If the rate of production is high, two such machines work side by side, one for

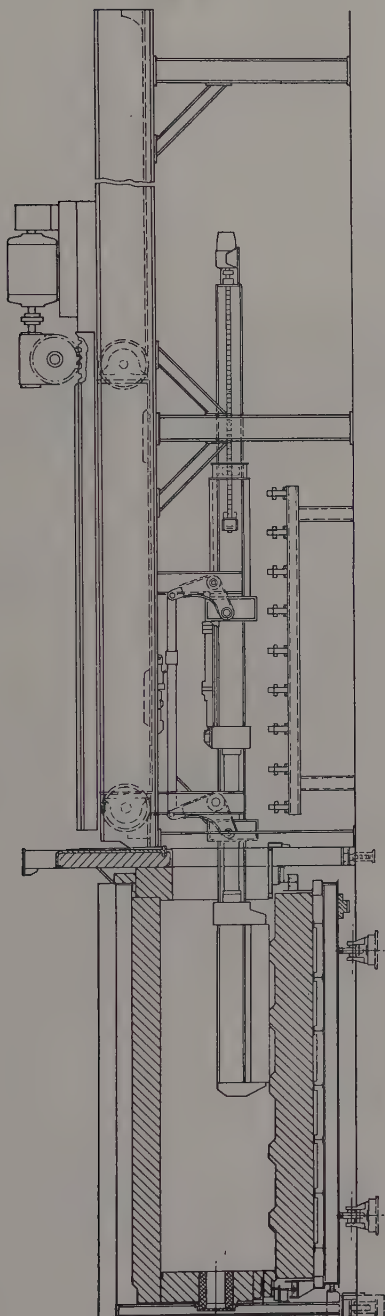


Fig. 189. Furnace charger with longitudinal clamping. Courtesy of George J. Hagan Co.

loading the rotating-hearth furnace, the other one for unloading it. If the door is wide enough, one machine suffices, provided it has lateral motion also. The machine can be used in front of multidoor batch furnaces, if it is provided with means for lateral movement. By means of interconnected bell cranks, the clamping device is given a small vertical movement. The machine picks up a billet from a

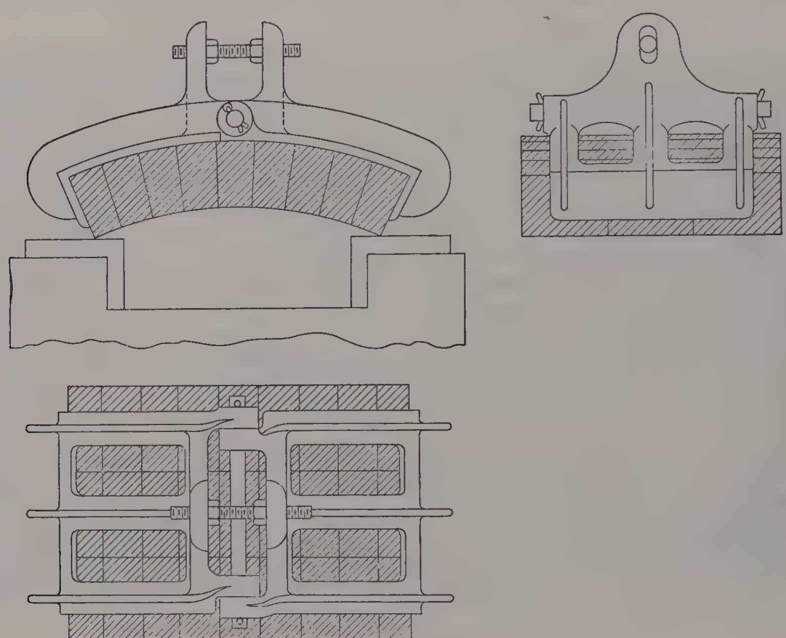


FIG. 190. Removable roof with clamping device.

roller table and deposits it in the furnace. The unloading machine reverses the process. Like other machines, this machine has limitations. The billet must not be too long in comparison with its diameter, to prevent buckling. This is especially true at temperatures around 2400 F. The seat of the operator is not indicated in the illustration. That seat is located to the right of the right-hand bell crank. The operator travels in and out with the clamping mechanism.

Heavy material is very cumbersome to handle, even with charging machines. For that reason furnaces for heavy and bulky material are frequently built with roofs which are removable.[1] The charge is then placed in the furnace by means of a crane after the roof has

[1] In the practice of melting malleable iron, removable roofs in short sections, similar to Fig. 190 are employed. They are called *bungs,* bung roofs, bung-top

been removed from the furnace, is heated with the roof in place on the furnace, and is finally taken out after the roof has again been lifted. While such roofs might be considered as part of the furnace proper, they are in reality labor-saving devices because they would not be used unless it were necessary to put bulky and heavy material into the furnace from the top. Figs. 190 and 191 are illustrations of removable roofs. In them, a metallic frame serves as an abutment. Since the frame and the refractory filling expand at different rates and since the frame can hardly be made strong enough to restrain the

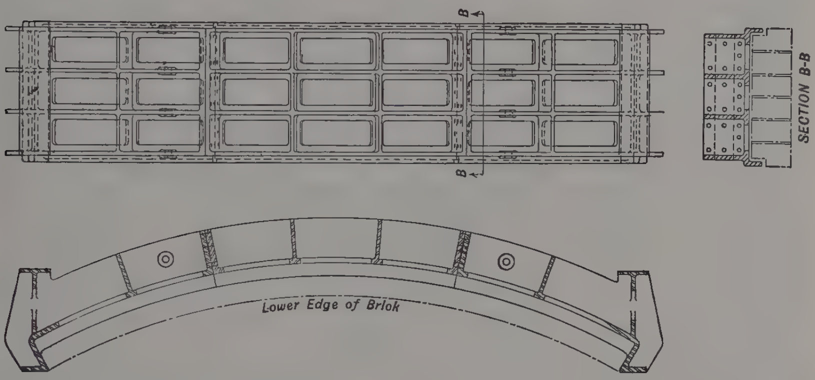


Fig. 191. Section of removable roof for a large annealing pit.

bricks from expanding, it must allow expansion by means of the rising of the arch, or else must be made of a ductile material which does not break when stretched. Furthermore, it must either have means for adjustment of the clamping of the bricks, or else the bricks must be selected so that temperature changes do not cause expansion or contraction. In Volume I, it is shown that firebricks lose in volume above a certain temperature. The loosening effect of the shrinkage is often accentuated by the fact that the expansion of the bricks below the critical temperature forces the metallic abutment apart.

From all of these causes, namely, the forcing apart of the metallic frame during expansion of the bricks, the shrinkage of the bricks at high temperatures, and their contraction at low temperatures, the

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roofs, or bung-top arches. The same names are frequently applied to other removable roofs of furnaces.

The roof over the combustion chamber of a malleable-iron furnace burns out quickly. The other bungs, which have been over the cooler part of the furnace, are then moved forward. This practice may well be imitated in certain reheating furnaces.

refractory filling becomes loose and drops out unless counteracting measures are taken. Fig. 190 represents a very common method of overcoming the difficulty. The frame holding the bricks is made of two sections which are hinged and are provided with lugs. By means of the lugs the two halves can be pulled together or pushed apart. In the illustration, the screw that connects the two lugs and is used for adjustment is very clearly shown; no comment is needed.

The force which the framework of a loose cover has to withstand can be judged from the principles laid down in Volume I for the design of roofs and arches. The horizontal thrust (which can be computed from the arch weight and the multiplying factor given in Volume I) tends to bend the metallic frame, in addition to producing tension. To withstand these forces, the metal work of removable arches is built very substantially. A strongly built arch is shown in Fig. 191, which illustrates the section of a removable roof for a very large pit-annealing furnace. This roof has several interesting features. It is designed so that the sections can be stacked on top of one another. It has the additional feature that overall expansion and contraction of the bricks is almost entirely eliminated by the alternations of four fireclay bricks with one silica brick. The heating and cooling of this roof is never rapid enough to injure the silica bricks.

Removable arches must be designed, of course, so that they can be lifted off with ease, for which purpose there are usually provided eye openings through which hooks of crane chains can enter. It is also advisable to remember that the stress distribution, when the arch is suspended from the crane, must not cause the metal work to take a permanent set or the bricks to become loose. It must finally be mentioned that there can be no permanent tie rods over the tops of furnaces that have removable tops. The furnace itself must be bound in a horizontal plane, strongly enough to withstand expansion. For that reason large furnaces with removable roofs are frequently built as pit furnaces in which either the surrounding earth or the adjoining pit assists in acting as an abutment.

Fig. 192 is a view of the movable roofs of pit furnaces of the type that is commonly referred to as a soaking pit. Roofs of soaking pits are moved aside quite frequently, because the blooming mills (which the pits serve) roll an ingot in an interval of time that ranges between 1 minute and 2½ minutes, depending on the size of the ingot and the speed of the mill. In the early years of the steel industry the covers were actuated by hydraulic power; they are now moved by electric motors which are mounted on the covers. Each cover is operated either by a single motor or else by two motors. With a single motor,

each supporting rail has depressions into which the wheels of the cover drop at the end of the closing stroke. If the cover is equipped with two motors, one motor serves for vertical lifting and the other causes horizontal motion. The operator of the covers is not exposed to heat.

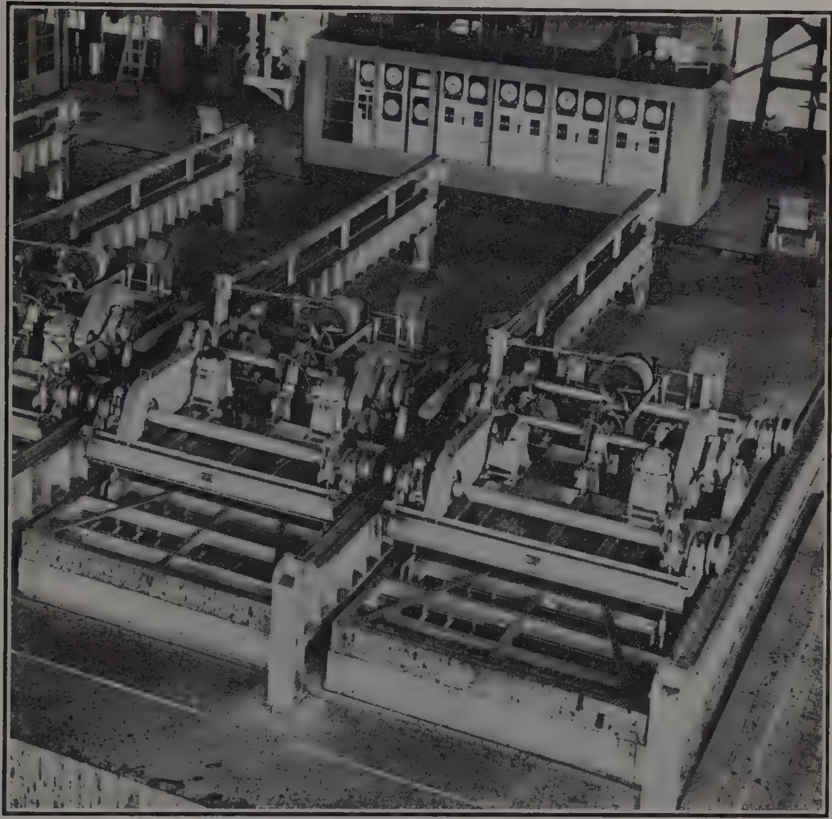

Fig. 192. Covers of soaking pits. Courtesy of Surface Combustion Corp.

He is in part guided by signals from the crane operator. Vertical movement of the whole cover may be avoided by the installation of an independently movable sand-seal apron; see Fig. 193. The non-water-cooled metal parts are made of a heat-resisting alloy. On account of the frequency of the opening and closing movements, covers of soaking pits must be made especially strong and durable. Frequently repeated cooling and reheating of the brickwork promotes loosening and disintegration of the bricks. The design illustrated by Fig. 192 has given good service. Since about 1950, soaking-pit covers

made of castable refractories are preferred to covers that are built up of individual bricks.

If furnaces with removable tops are charged and emptied while the material and the furnace are comparatively cold, common cranes can be used. If hot material is charged into pit furnaces with removable

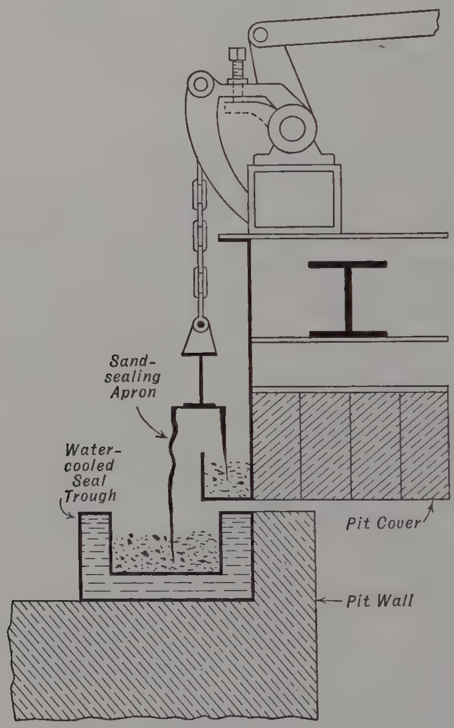

FIG. 193. Vertically movable sand-seal apron on soaking pit.

roofs, or is taken from them, ordinary cranes are very unpleasant for the attendants because the material tends to swing from the crane chain and must be kept from swinging by a man standing alongside the open furnace pit and guiding the material by means of a rod with a hook. The heat radiated from the open pit to the attendant is so extreme that the guiding is frequently poor and the hot material bumps against the side of the furnace or against the roof, injuring it and knocking down the brickwork. For that reason, pit furnaces are now served by stiff-legged cranes, so-called soaking-pit cranes, the working part of which is illustrated in Fig. 194.

Long and heavy pieces, such as large caliber guns, are sometimes

heated in pit furnaces. This practice needs very tall buildings with expensive cranes. A device is needed for picking the long pieces up from a horizontal position, for the purpose of lowering them into the pit, and vice versa, when the heated blank is taken to the forging press. For these reasons, long and heavy pieces are frequently heated

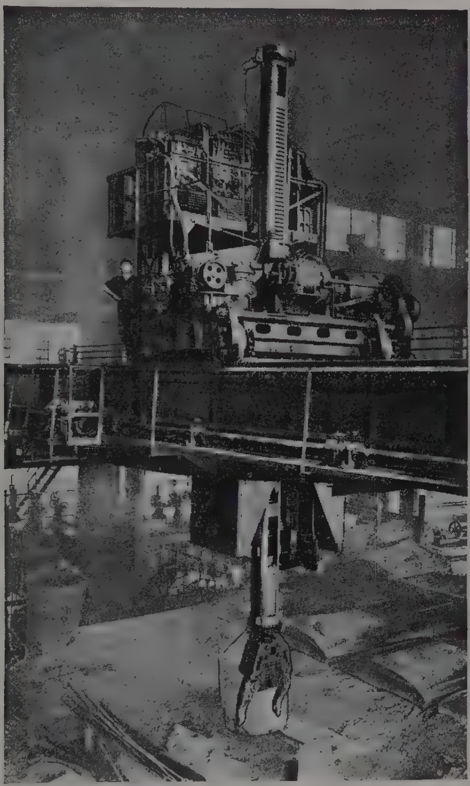

Fig. 194. Stiff-legged crane for charging pit furnaces.

and annealed in car-type furnaces. From the thermal standpoint, that is to say, with regard to uniformity of heating, the ordinary car-bottom furnace has no advantages to offer. The reason for its existence lies in the advantages which it offers with regard to the mechanical handling of the charge. Fig. 195 shows a car-bottom furnace for annealing long objects such as ship shafts. Fig. 196 is a section through a furnace in which heavy forging ingots (weighing up to 250 tons) are heated. The drawing is idealized; in reality, the four burners do not lie in the same plane. Fig. 197 drives home the fact

that the car-bottom furnace is the only furnace that can serve for heating the enormous ingot there shown. Even heavier ingots have

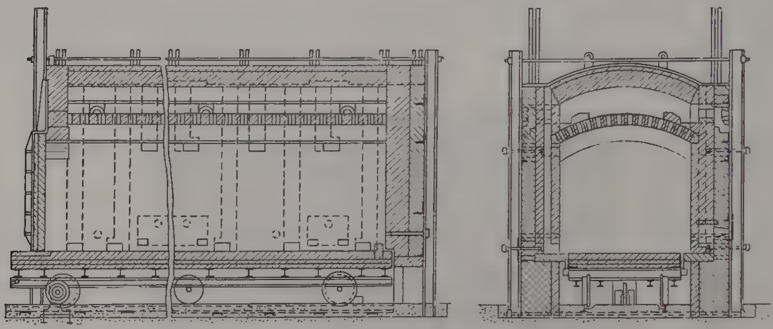

FIG. 195. Car-type furnace.

been heated in the same furnace. When a heated ingot of that size is picked up from the car, the superintendent does not stand as close by as he does in Fig. 197.

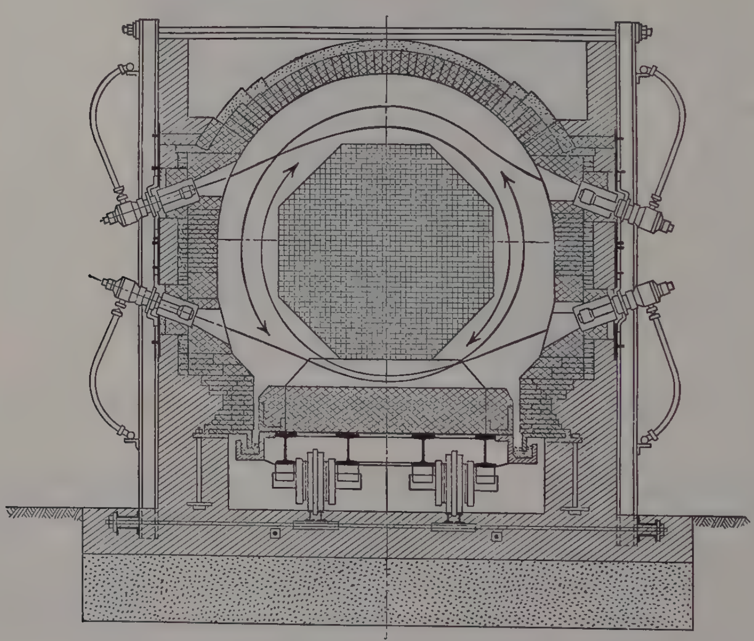

FIG. 196. Car-type furnace for very large ingots.

The car-bottom furnace also has disadvantages. When the car is pulled out of a hot furnace, the radiation from the furnace is

directed towards the floor. This floor must not be made of Portland cement concrete, but must either be covered with firebricks or else be made of refractory concrete. Pulling the car out of the hot furnace means a great loss of heat, unless a new charge can be pushed in without delay. In annealing furnaces the heat is lost in another way:

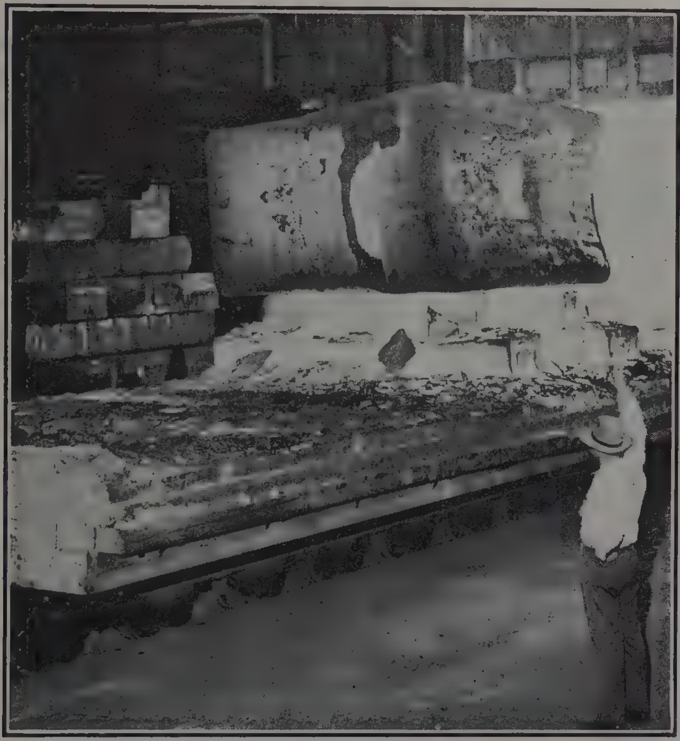

Fig. 197. Loading a furnace car. Note the large number of wheels. Courtesy of United States Steel Co.

furnace and charge are cooled down together. In those car-bottom furnaces which are fuelfired, it is often difficult to get the top of the car as hot as the top of the furnace, and cold spots are likely to result, unless the charge is elevated from the floor and rests on supports. The lower the furnace temperature, the higher the supports must be (and can be). Furnaces in which a temperature as low as 1200 F is carried at some time or other are equipped with auxiliary bottom burners or with large excess-air burners for the purpose of temperature equalization. Blocks for supporting the charge are necessary for another reason. They afford clearance for chains or gripping

tongs. In order to reduce heat losses it is customary to place insulating material between the firebricks of the car and the steel work upon which it rests. If material is to be piled directly on the car, the hearth is made of vitrified brick, which withstands abrasion better than ordinary firebrick.

All car-type furnaces must have a seal for preventing free circulation of the gases between the space underneath the car and the heating chamber. In a few car-type furnaces, water seals have been used; but by far the greatest number of car-type furnaces are provided with a sand seal because the end wall of the water container interferes with endwise movement of the car and also because water evaporates and increases scaling, if the vapor enters the heating chamber. A sand seal which has given good results, as far as sealing is concerned, is shown in Fig. 198. Owing to the moving of the car into and out of the furnace, the sand has a tendency to distribute itself irregularly and to pile up at one end or the other. In most cases the angle iron which forms the seal in the sand is fastened rigidly to the car. In the illustration shown, it can adjust itself up and down to a certain extent, whereby greater safety against leakage of gases is secured. The sand seal in Fig. 198 has one fault; it projects beyond the car. Sand seals should be so designed that neither the sand trough nor the blade can be damaged when the car is out of the furnace. The seal of Fig. 199 has this desirable feature. In addition, it is a double seal. The two sand seals described above are applied only to the sides of the car. It is, however, possible to seal the rear end of the car, as shown in Fig. 200. A horizontal tongue or blade in the furnace enters into a sand pocket of the car. At the front or door end of the car no sealing arrangement is needed. Any hot gases passing under the door cannot reach the space under the car, but go into the room. In many recently built car-type furnaces the door is an integral part of the car. A seal for all four edges of the car requires entering the car at a slightly elevated level and then lowering it into the sand seal. This method has been proposed, but so far as the author knows has not been adopted in practice. In conclusion, it may be mentioned that very fine Silocel powder has been found to make a better seal than sand makes.

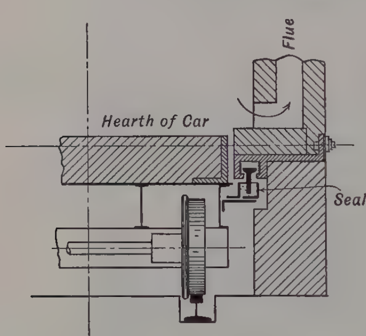

FIG. 198. Sand seal for car-type furnace.

The moving of heavy cars involves time and hard labor if it is to be done by hand. For that reason cars are usually moved into and out of furnaces by what is commonly known as a car puller. A car puller

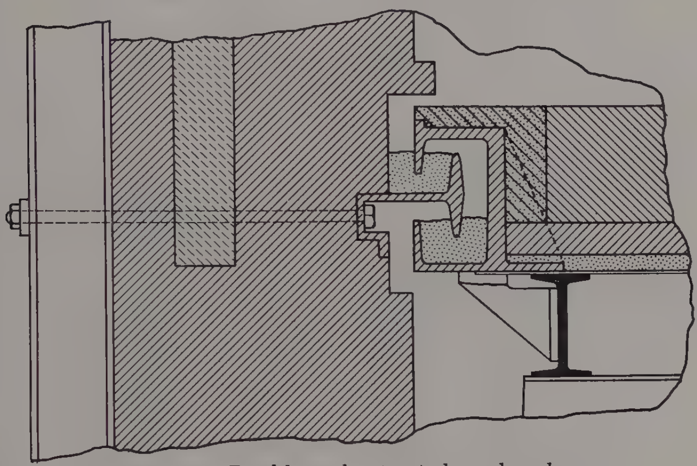

FIG. 199. Double and retracted sand seal.

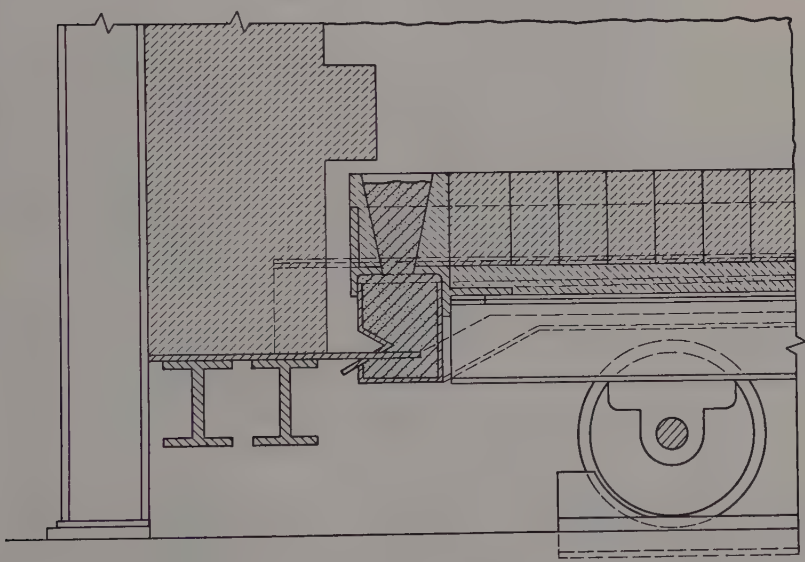

FIG. 200. Sand seal at rear of furnace car.

is diagrammatically shown in Fig. 201. It consists of an electric motor that is working through a set of speed-reducing gearing and is winding a cable or a chain in one direction or the other. The car is

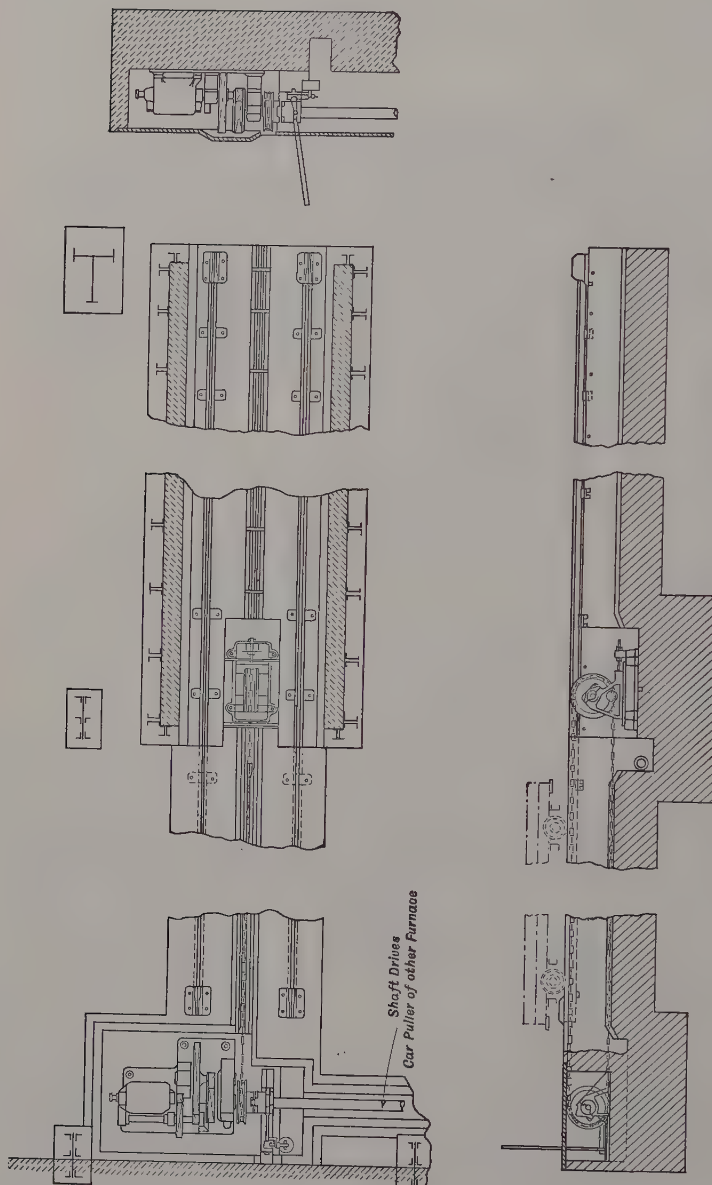

FIG. 201. Car puller operated by reversible electric motor. Chain pulley is connected to driveshaft by jaw clutch.

hooked to one or the other end of the chain or the cable and is thereby moved into the furnace or out of it. A car puller is not needed if a locomotive or a heavy tractor is available at the right time. The car may also be motorized.

Before the time when suitable roller bearings became available, furnace cars traveled on balls that rolled in V grooves. Ball-supported cars were used under furnaces that were coalfired; the balls were not affected by smoke or ash. Furnace cars now travel on wheels that are equipped with roller bearings. The bearings must withstand a temperature of 350 to 550 F. This temperature is influenced by the application of insulating material in the car and by ventilation of the space under the car. It is desirable to have the wheels that travel on one and the same rail equipped with two flanges, and to omit flanges on the wheels that travel on the other rail. In the hot furnace the car expands; if the wheels for both rails are equipped with flanges, gripping and binding occur, unless much clearance is provided. (The same principle was applied in the ball-supported cars. In the center of the lower surface of the car was an inverted V guide; the car rested with flat, plane surfaces on the outer rows of balls.) The number of wheels must be adapted to the maximum load that the car is expected to carry, including the weight of the car itself.

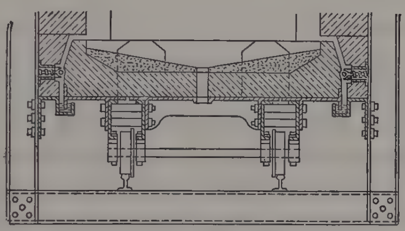

FIG. 202. Furnace car arranged for slag removal.

For special purposes car bottoms are specially equipped. For the enameling of ceramic materials, for instance, they are provided with prongs which carry on points only. For material which is to be heated almost to a welding heat (given a "washheat"), the cars are equipped with slag holes toward which the floor slopes. Such a car is illustrated in Fig. 202. It is evident that cars with all sorts of special hearths can be designed to take care of the manifold requirements of industrial heating.

It may be mentioned that cars are used also for the purpose of moving material continuously, or more or less continuously, through a furnace. The type of car used for that purpose is considered later under Continuous Furnaces.

Labor-Saving Equipment for Continuous Furnaces. Whenever the conditions are such that continuous transportation of the material through a furnace is economically possible, that method of transporta-

tion is adopted, because it effects a saving of labor far beyond that which can be achieved by any other method. As a matter of fact, the continuous furnace was introduced principally on account of its labor-saving features. It is quite evident that the use of continuous furnaces is predicated upon a fairly continuous production because continuous furnaces, that is to say, furnaces through which the material moves continuously, are not adapted to intermittent operation.

In the present chapter only the labor-saving features of continuous furnaces are dealt with. The fuel-saving features are analyzed in Chapter IV of Volume I. The method of moving material through a furnace varies greatly with the temperature of the furnace, with the shape of the material to be conveyed, and with the size of the individual pieces to be handled.

It may be justly stated that, in the invention and design of continuous furnaces, the inventive genius displayed by Americans in the field of mechanical engineering has shown itself ready to meet any demand. Given a sufficiently large demand for heating quantities of rather uniform shapes of material, the engineer invariably develops a continuous furnace for doing the work. So insistent is the demand for the mechanical conveying of material through furnaces that considerations belonging strictly to mechanical engineering frequently overshadow those of combustion engineering or heat engineering in the drawing rooms and shops of modern furnace builders.

The following classification gives an idea of the great variety of conveying systems for continuous furnaces:

A. Straight-line motion.
- (*a*) Pusher.
    1. Direct.
    2. Indirect.
- (*b*) Puller.
- (*c*) Rollover.
- (*d*) Conveyor.
    1. Chain.
    2. Belt.
    3. Roller.
    4. Moving car.
    5. Overhead rail.
    6. Special-purpose conveyor.
    7. Material its own conveyor.
    8. Shaker hearth.
- (*e*) Rocker bar (walking beam).
- (*f*) Vertical type.

B. Circular motion.
- (*a*) Rotating hearth (doughnut type and dinner-plate type).
  1. Outside charge, internal delivery.
  2. Outside charge, outside delivery.
- (*b*) Stationary hearth, moving furnace.
- (*c*) Other circular conveyors.

C. Helical motion.
- (*a*) Smooth drum.
- (*b*) Ribbed drum.

Straight-line Motion; Pusher-type Furnaces. A very popular and effective method of moving the material through a furnace consists in pushing it over a hearth. Furnaces operated in this manner are known as *pusher-type furnaces*. Several features concerning the hearth construction of these furnaces are dealt with in Volume I, under the heading, Strength of Hearth. If steel is to be heated to rolling or forging temperatures, the pusher type of furnace is the most practicable and most widely used continuous furnace with straight-line motion.

Furnaces of the type under discussion are built either with end discharge or with side discharge. End discharge or gravity discharge is preferred in many cases, because several furnaces equipped with end discharge can be placed side by side and can discharge the heated material onto a conveyor. The total furnace capacity can be increased by the addition of more furnaces as the demand for heated material grows. A side-discharge furnace requires a man for pushing the stock out of the furnace.

Furnaces of the side-discharge type must be used when long bars of comparatively small cross section have to be heated for rolling in continuous mills. In order to avoid excessive speeds at the finishing pass of the mill such bars must enter the first stands of the mill very slowly. A long, heated bar would become very cold at the rear end if it came out of the furnace all at one time and were lying on a guide or a roller table. For that reason the rear end of the bar must be kept in the furnace while the bar is going through the first slow-speed passes of the continuous mill. The capacity of these furnaces is strictly limited. When the mill rolls heavy sections through the high-speed finishing pass, the output of the mill in tons per hour is increased and a great deal of steel must be heated in pounds per square foot of hearth an hour. When the mill rolls very light sections, the amount of steel to be heated in the furnace in unit time is comparatively small. The result is that the furnaces are designed for an average section and that, whenever heavy sections are rolled, the furnace capacity is insufficient. In that

case the furnace is forced and furnace repairs run up considerably. It is possible to bring preheated bars into the furnace, but this method of increasing the capacity does away with the labor-saving features which are so highly prized in continuous-furnace practice.

Continuous furnaces of the pusher type must be equipped with trouble doors. The material which is pushed through the furnace is not always of uniform shape and is not always made with edges sufficiently square to assure uniform pushing.

Material with round edges, or pieces of a very crooked shape (for instance, sheared billets), will occasionally "climb up"; that is to say,

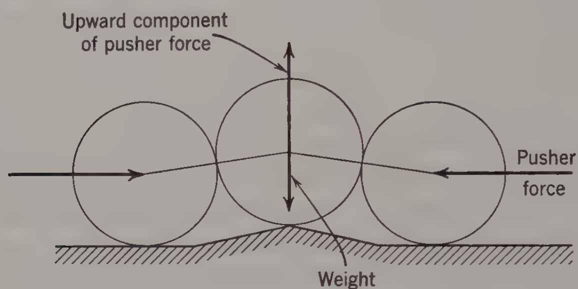

FIG. 203. Lifting effect of irregularity in hearth.

one piece will come to lie on top of another, or several pieces may pile up, one on top of the other. Any irregularity or unevenness in the hearth is a contributory cause for piling up, a fact which is convincingly illustrated by Fig. 203. It is easily seen that bars with circular cross section are prone to get out of line. Whenever the upward component of the pusher force exceeds the weight of the billet, the billet is lifted up.

Several different measures have been taken for reducing the tendency to pile up, especially for thin and therefore light material. The length of the furnace (in the direction of the pusher motion) has been made small. The skids have been made concave, as illustrated by Fig. 204, for the purpose of having the pusher force exert a downward component. Unless the irregularities in the billets or in the hearth are extreme, the concave skids prevent piling, except for billets of less than 1¾ in. thickness. Plates and sheets are not pushed through furnaces. They either buckle or slide over one another.

A favorite method for reducing the danger of piling up consists in inclining the hearth downward in the direction of movement. Even a small inclination utilizes gravity for reducing the pusher force. If, for instance, the angle of inclination is 10 degrees between hearth and a

horizontal plane, the force that is required for pushing is reduced 17.4 per cent, whereas the force that holds the billet against the hearth is reduced less than 1½ per cent.

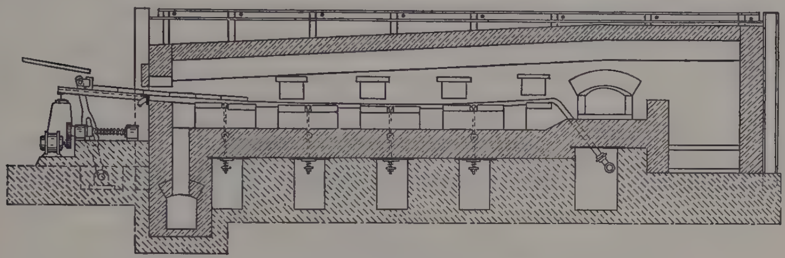

Fig. 204. Continuous furnace with concave skid pipes.

Still another method, which has been applied with success in the pushing of irregular bodies such as railroad rails and in pushing of billets with round corners is illustrated in Fig. 205. The pusher force is, of course, greatest at the pusher end and drops down to zero at the end of the line. The danger of buckling is greatest at the pusher end. Buckling is prevented by rigid beams that allow only a very small rise of the billet or by heavy beams that rest on the billets. This latter method is illustrated in Fig. 205, already referred to. With larger

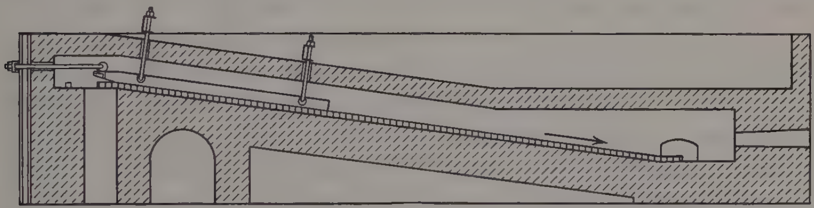

Fig. 205. Device for preventing the buckling of the charge in continuous furnaces.

billets, piling up occurs less frequently. They remain straight after leaving the rolling mill, and, moreover, weight is in their favor in holding them down. Much trouble can be prevented by rolling billets and slabs with almost square edges.

At the other extreme of the range of material sizes we come to the difficulties that arise when pusher-type furnaces are used to heat heavy sections. Some of these difficulties are mentioned in Volume I. The principal difficulty is to combine a satisfactory pushing apparatus with the arrangements for obtaining a uniform temperature throughout the heavy ingot, bloom, or slab. In the early years of the present century

many patents were granted on devices for turning the ingot or bloom over, so that the ingot or bloom will expose, at the soaking end of the furnace, the cold side (including black spots) to the heat, and thereby will become more uniformly heated throughout. On account of the cost of maintaining these schemes, very few have survived.

One of the simplest and most successful turnover devices originated in the Pacific Northwest of the United States and is shown in Fig. 206. By means of this device it is possible to give the ingot either a quarter turn or a half turn. From Fig. 206 it is plain that a bar which is rigidly held and yet quickly adjustable can be slid into the furnace and

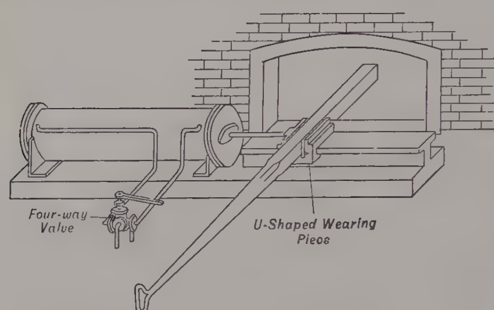

Fig. 206. Ingot manipulator.

placed against the ingot or bloom in such a manner that it will either push the ingot along or turn it over, depending upon the elevation of the bar. As soon as compressed air is turned into the power cylinder, the ingot will be turned over if the bar touches the side of the ingot near its top; while the action is that of a pusher only, if the bar rests against the bottom of the ingot. The slide or crosshead which holds the bar is guided by a rail and is equipped with a U-shaped wearing piece, which can be replaced after wear has occurred. A small stream of water runs onto the end of the bar in its normal position at rest outside of the furnace, so that the bar will not become overheated by repeated use in the hot furnace.

Unless the furnace end of the manipulator bar is spear-shaped, the ingots or blooms obviously must be separated before the manipulator bar can enter between them. Automatic separation can be effected in several ways. A sudden increase in the downward slope of the skid pipes separates the ingots or slabs at the top. Pushing the steel off the end of the skid pipes is another effective method. Ingots and blooms of moderate size, say, to 8 in. in diameter (or length of side), can be allowed to drop over the edge of the water-cooled pipe skids, onto the

brick forehearth, as indicated diagrammatically in Fig. 207. Heavy ingots to 23 in. in diameter are, as a rule, not dropped onto the forehearth as indicated, on account of the damage which they would do to a soft, slaggy hearth and because they could never be heated with any degree of uniformity on a ventilated or water-cooled hearth. The ingot

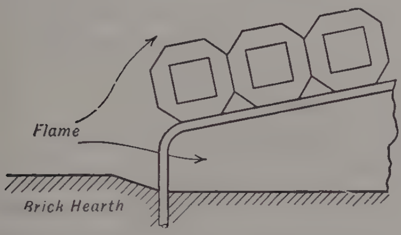

FIG. 207. Soaking end of continuous furnace. Ingots drop from pipe skids onto soaking hearth.

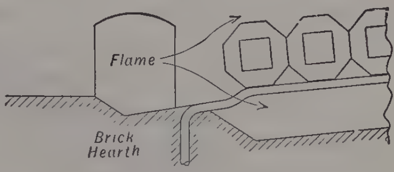

FIG. 208. Soaking end of continuous furnace, with pipe skids to roll ingot over when pushed onto soaking hearth.

or bloom may be caused to turn over by giving the skid pipes a peculiar shape such as shown in Fig. 208, or else the ingot may be pushed onto the forehearth, without being turned over automatically, where it may be moved around and turned over by a manipulator of the type illustrated by Figs. 206 and 187.

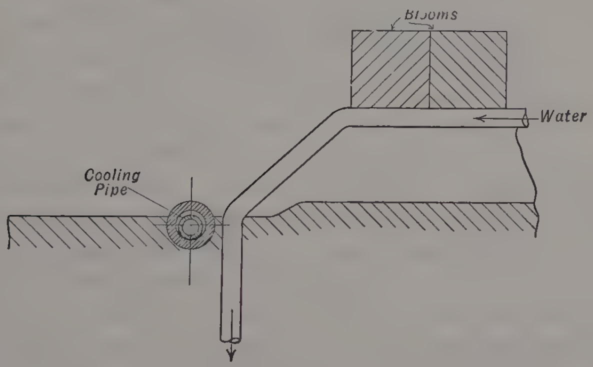

FIG. 209. Method of turning blooms on forehearth.

The skid pipes of Fig. 208 break after a short time, on account of the impact caused by the falling of the heavy weights. The design represented by Fig. 209 was found to avoid the troubles incident to the pounding by blooms or ingots. At the foot of the skid pipes, a seamless tube with extra-thick walls is imbedded in the magnesite hearth. It is

water-cooled by a smaller pipe inside it, and is firmly anchored in the sidewalls. The blooms turn over through 180 degrees, exposing the cold side to the heat. In the absence of the water-cooled pipe at the bottom of the drop the blooms turn over as desired for a short time only. The corners soon make so deep an indentation in the forehearth that the blooms stick there without turning.

The troubles which arise from turning over ingots or blooms disappear if the continuous furnaces are equipped with zone heating, as discussed in Volume I. And troubles caused by slag disappear, if the furnace temperature is held down to 2300 F.

If ingots are heated in a continuous furnace, every other ingot is turned end for end. This arrangement serves a double purpose. The ingots do not wander off the skids, and the fins at the ends of the ingots are kept out of each other's way. If every other ingot is turned end for end, a turntable is usually provided at the discharge end of the furnace for the purpose of turning every other ingot and bringing the correct end to the mill.

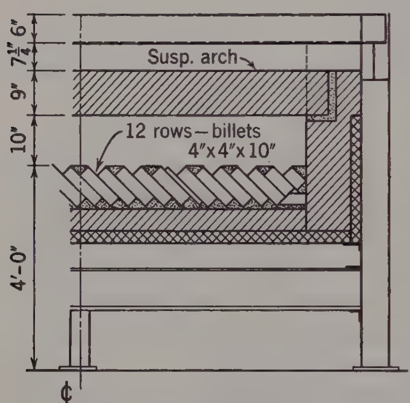

Fig. 210. Pusher-type furnace with V grooves.

Short stock ("slugs") of square section is often pushed lengthwise, while resting on edge in refractory grooves (as illustrated in Fig. 210, which shows a half section through a furnace). Since standard bricks are used, the distance between adjacent grooves is not great enough to place 4 in. by 4 in. slugs in adjacent grooves. Every other groove is not filled by steel but by chrome ore, so as to avoid attack (of the bricks) by scale. The billets fit into the grooves no deeper than is necessary to prevent their toppling over sideways. The bricklaying job must be done carefully. If a brick projects into a groove, much damage is done.

If larger and larger square billets are heated on edge, the pressure between metal and refractory grows, unless the supported fraction of the length of the side is increased. If that be done, the unheated portion becomes too great and the bottom remains cold. For large squares, water-cooled skids are used. They absorb so much heat that the very bottom of the square section stays cold. In order to eliminate the non-uniformity, extra-hot products of combustion are sent through ducts under the stock, as illustrated by Fig. 211, which is a

half section through a furnace with water-cooled skids. The steep temperature drop from flame to water temperature causes high cost of maintenance. The slugs (square plates) drop on a forehearth, on which they are distributed by the heater, who must exercise judgment with regard to proper uniformity. Pusher furnaces of this type may be called semi-labor-saving.

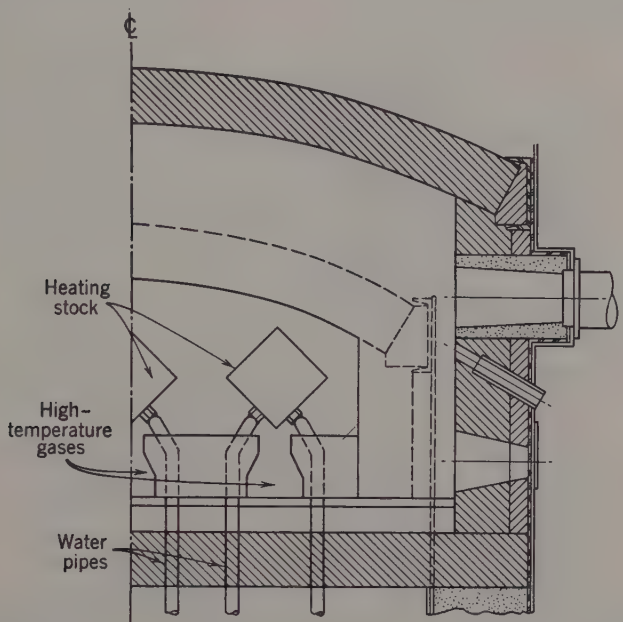

FIG. 211. Continuous furnace with water-cooled V grooves and with heating from top and from bottom.

One of the most important pieces of labor-saving equipment in connection with continuous furnaces is the pusher which moves the stock through the furnace. Pushers are either of the fluid-displacement type or of the electric-motor type. In the displacement type a fluid, such as compressed air, steam, oil, or water under pressure, acts upon a piston and moves it forward. The motion is then transmitted to the stock, directly or by means of a lever mechanism. In the electric-motor type the motor operates a screw, a rack, or a crank through suitable gearing, and the motion is again transmitted to the stock by means of mechanisms.

No matter what type is used, the following remarks are of importance. The pusher works not continuously but intermittently. In

consequence, the material to be moved starts from rest with every forward stroke of the pusher, which means that the friction of rest must be overcome. After motion has begun, friction is, of course, reduced to a somewhat lower value. Tests indicate that the friction coefficient between red-hot steel and cold steel skids is approximately 40 per cent at the start (it rises above 50 per cent, if the steel is scaled), and drops to about 30 per cent if motion is maintained. For white-hot temperatures the friction coefficient is smaller.

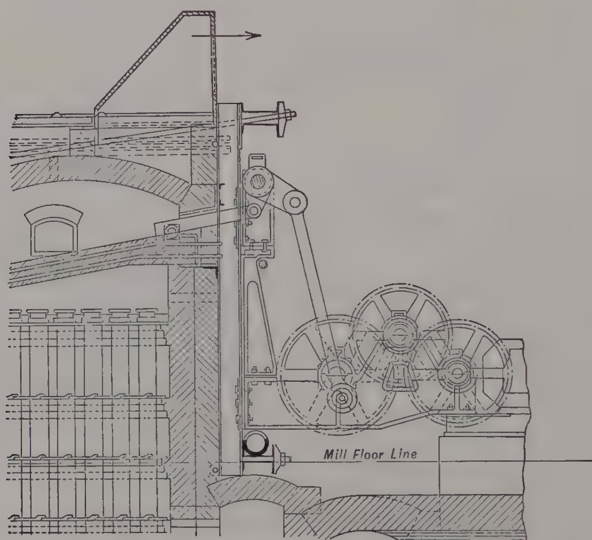

Fig. 212. Motor-operated crank-type pusher for continuous furnaces.

When pieces of varying size are to be pushed through a furnace, the stroke of the pusher must be adjustable. If the pusher is of the fluid-displacement type an adjustable lug on the piston rod strikes a lever or other object that closes a valve in the fluid-supply pipe. If the pusher is operated by an electric motor, an adjustable limit switch cuts off the power and applies the brake. In crank-operated electric pushers, an example of which is shown in Fig. 212, the crank may make a whole revolution for each billet. In that case, the length of the crank and of the connecting rod must be adjustable, if billets of different sizes are to be pushed.

A screw-operated electric pusher is illustrated in Fig. 213, whereas Fig. 214, shows a design in which an electric motor drives a rack through suitable reduction gearing and through a pinion. In this design the straight-line motion of the rack takes the place of the straight-

line motion of the piston rod in the hydraulic pusher. It will be noted that the pusher head disappears below the rails when it is drawn back. While it is in that position, the bars to be charged are brought to position above and in front of it by the transfer chain. The motor operating the pinion is started, and as the pusher head moves forward it also rises above the level of the rails and pushes the bars into the furnace.

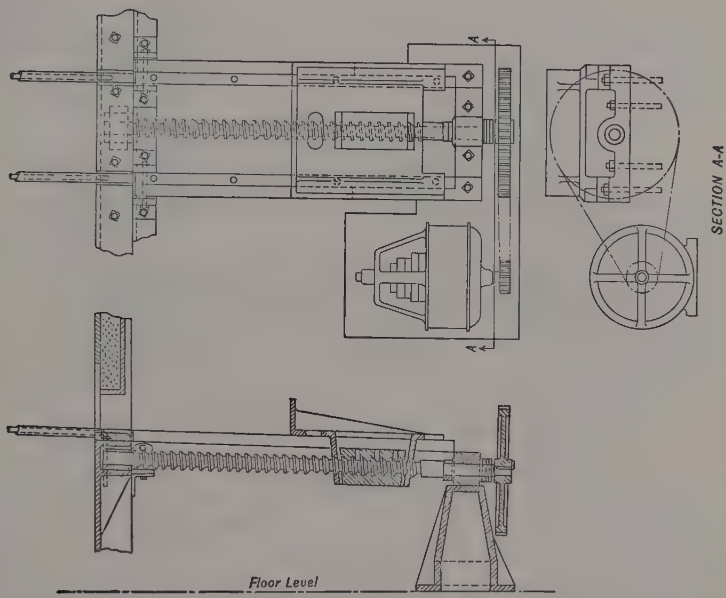

FIG. 213. Motor-operated pusher of the screw-and-nut type.

Although hydraulic pushers offer the advantage of direct action at the furnaces and of quick adjustment of stroke, they have serious disadvantages. Pipes that carry hydraulic pressure are often in the way and are otherwise troublesome, especially in the winter. But an electric cable can be installed without being in the way of other things, and electricity does not freeze. In consequence, modern pushers are operated by electric motors except when the furnace serves a near-by hydraulic press. The advantages of both systems have been combined for operating the pushers of a group of small or medium-sized furnaces. An electrically driven pump, controlled by a pressure switch, delivers a light oil into an accumulator tank, from which the oil flows to the pushers and back into the sump of the pump. However, this arrangement is a fire hazard.

The pusher has to exert the whole frictional force for moving the stock through the furnace. This force is of considerable magnitude in connection with large furnaces, and the pusher must be well anchored. If the stock is pushed over skid pipes it is customary to fasten the skid

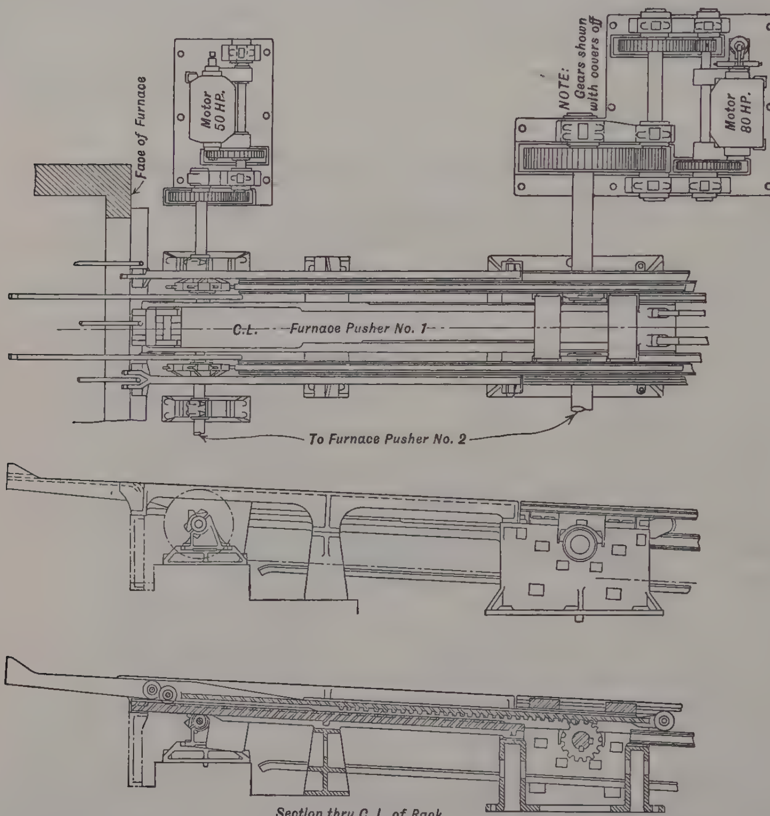

FIG. 214. Furnace pusher of the rack-and-pinion type. This pusher is combined with a transfer for steel bars.

pipes rigidly to the pusher and to let them expand freely at the hot end of the furnace. By this method of design the forces become self-contained between the pusher, the stock, and the skid pipes.

Continuous furnaces of the pusher type that are built for side discharge must be equipped with a machine for removing billets and blooms, unless the billets are small enough to be removed by hand. The power-operated device (pushout) may be a traveling manipulator but is more often a fixed lateral pusher. A power-operated pushout

is diagrammatically illustrated in Fig. 215. The operator places the water-cooled push bar behind the end billet and steps on a pedal, by which action fluid pressure is admitted to a hydraulic cylinder. Its piston pushes an idler roller up against the push bar, which is thereby forced up against a continuously rotating power-driven roller and is pushed into the furnace by pinch-roller action. In order to make sure that the pusher action is in the direction of the billet, the pusher bar is hydraulically movable at right angles to itself. If the furnace is driven beyond its built-in capacity, scale melts, and the billets stick together. In that case the operator must pry the billets apart.

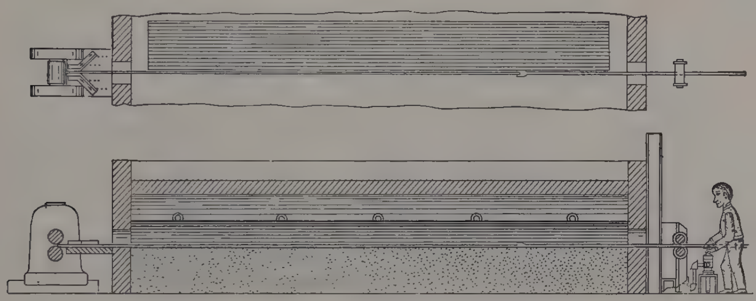

Fig. 215. Power-operated pushout rod.

If the billets are very long, they are not only pushed out through the side of the furnace but they are also carried in through the other side (at the cold end). The standard equipment serving this purpose is illustrated by Fig. 216. Live rollers outside the furnace cause the billet to enter the cold end of the furnace. In the furnace, water-cooled rollers, set slightly askew, take over. The skewing holds the entering billet against the rear of the furnace. The lower illustration shows that the rollers project a small distance above the skid rails. The entering billet bumps against a spring-cushioned stop.

Pushers not only move ingots, blooms, and billets through furnaces, but transport a great variety of other material that is loaded on cars, on trays, and in containers. In tunnel kilns, the stock or charge is loaded on cars, with refractory tops. The cars are loaded with ceramic material, piled sheets, demolition-bomb bodies, round billets for piercing, and still other material that cannot be pushed by direct contact. If the charge rests on metallic trays, they must be strong enough to withstand the pusher force at furnace temperature. A mitigating feature is the fact that the trays are cold at the place where the pusher force is greatest. Another consolation is that the trays can be straight-

ened, if they were deformed in the furnace. Fig. 217 shows a furnace tray in top and bottom views. The tray is equipped with a flat slide and with a U-shaped slide. This method of guiding corresponds to

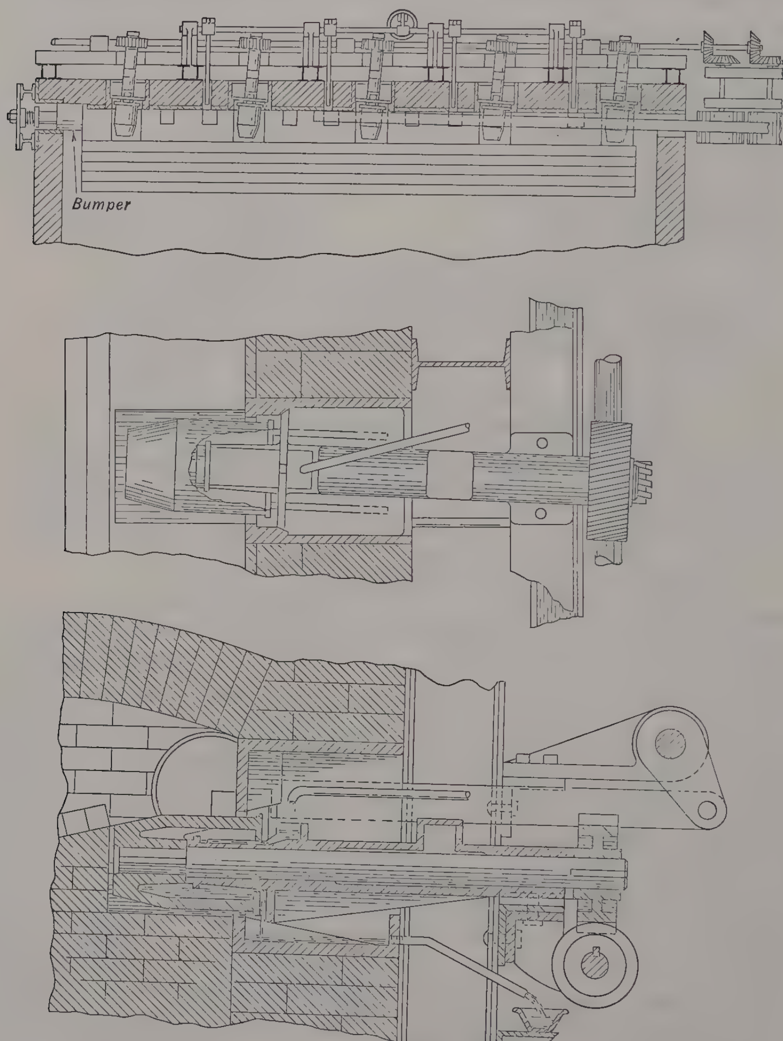

Fig. 216. Power-driven rollers for carrying long billets into furnace.

providing, under furnace cars, flanges on the wheels for one rail only. Metallic trays are seldom used for furnace temperatures in excess of 1700 F.

If short (in the direction of pushing) pieces such as round bars for

piercing are loaded on cars that are to be pushed through a furnace, a special manipulator must be provided for picking the pieces off the car one by one, while the car is still in the furnace, and for depositing them on the roller table that leads to the mill.

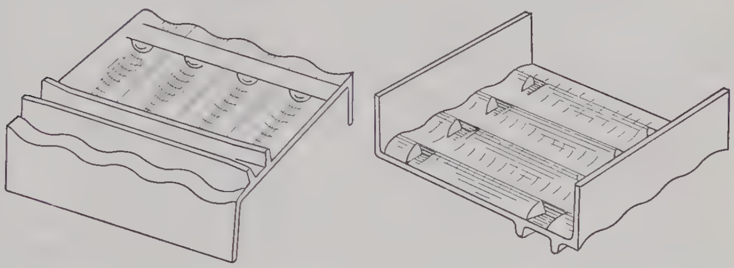

FIG. 217. Lightweight alloy tray for pusher-type furnace.

Moving material on trays through a furnace involves a disagreeable task, namely, that of returning the containers from the discharge end to the cold or charging end. All sorts of conveyors have been used for returning the containers, even over the top of the furnace or underneath the furnace.

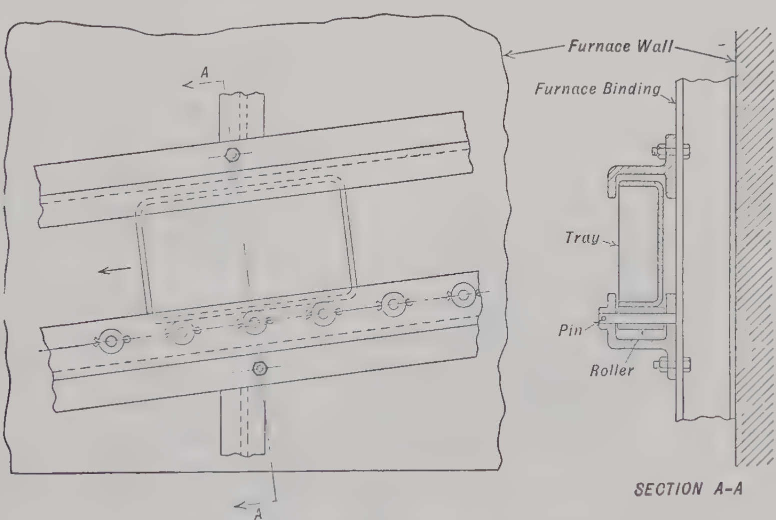

FIG. 218. Method of returning containers to charging end of furnace.

Monorails are also used for taking the trays back along the side, but one of the simplest schemes is that of providing an inclined plane along one side of the furnace, placing the tray on rollers and allowing it to go back on these rollers to the charging end. Fig. 218 indicates diagram-

matically how this has been done for flat trays. The trays are placed on end, that is to say, they are turned in such a way that they stand up and occupy very little space laterally. They run on rollers, which are shown in the illustration, and are guided so they cannot fall over. This device has been very effective and very economical of labor. In shops with ample space the trays are returned on wide rollers, such as are used for the gravity-conveying of bricks. This arrangement is useful if trays of different sizes are to be transported.

The return travel of trays can be put to good use, if hardening furnace, quench tank, washer, and draw furnace are arranged roughly like the four sides of a rectangle. Such grouping of equipment is illustrated by Fig. 219. All movements of the trays are power-operated, except moving the trays from the discharge end of the draw furnace to the entrance into the cyaniding furnace. Men are needed at that station for unloading and loading of trays. No labor would be saved by mechanizing the transfer. Pushing and pulling at all other stations is effected by motor-driven chains. The illustration is so well marked that no additional comment is needed.

Rollover Furnace. This furnace is the original continuous type. It is anything but labor-saving, because men must reach through side doors, and must, by means of tongs or crowbars, turn the ingots or blooms over, thus rolling them from the cold end to the hot end. In spite of the advantages of the very uniform heating which this type offers, it has disappeared for general purposes, on account of the disagreeable labor which it involves. It still survives in tire furnaces, through which round slices of ingots or forged disks are rolled by hand. It also survives in the heating of rounds for making seamless tubes, especially in countries with low labor cost. However, attempts to get rid of the onerous labor were made even in such countries. About 1924 a machine for rolling round bars down an inclined hearth was built in Germany. The machine moved on inclined rails along the side of the furnace. It reached into the furnace with a spear which could swing horizontally and vertically and which, of course, also moved with the machine. The use of this well-thought-out machine was given up, because the operator, having his eyes on the furnace interior, knocked down the piers between the doors.

For heating small rounds, such as are needed for forging 90 mm shells, a rolldown furnace has been operated with low cost of labor. A furnace serving this purpose is illustrated in Fig. 220. The attendant who operates at the discharge end stands 10 to 12 feet away from the furnace. He rakes the billets down, reaching up to the place where the billets become too soft to roll by gravity. If the billets in the cold

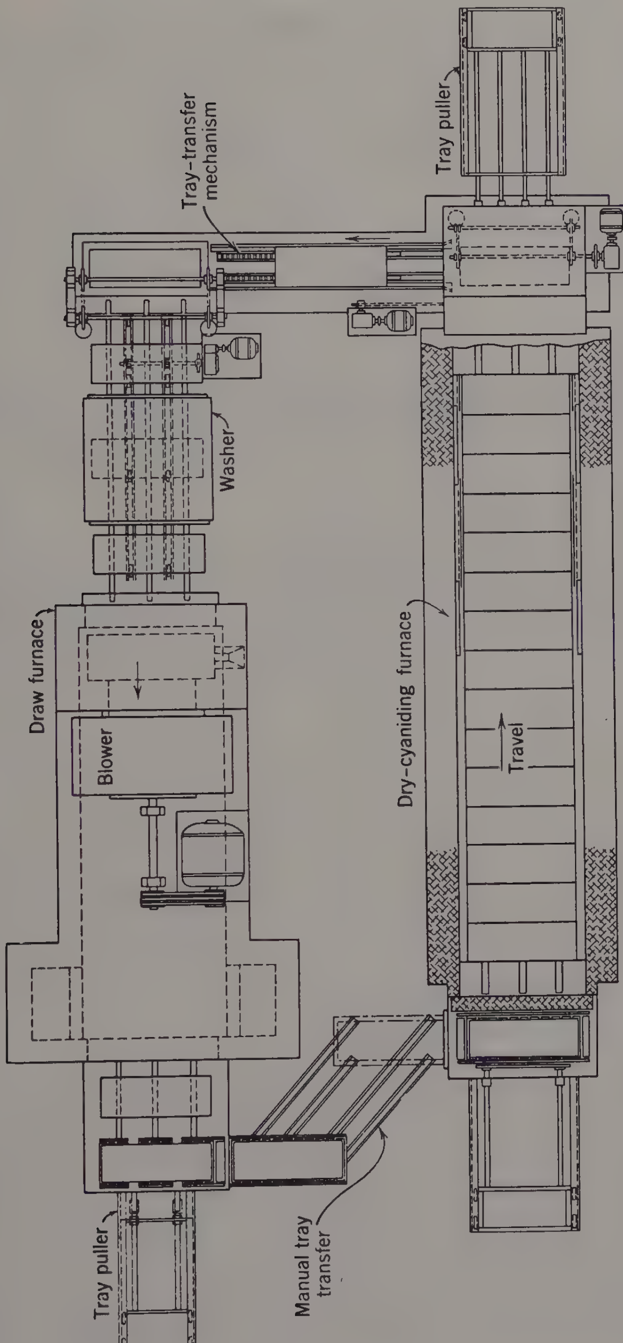

FIG. 219. Equipment for moving trays through hardening furnace, quench tank, washer, draw furnace, and back to starting point. Courtesy of Westinghouse Electric Corp.

section fail to roll, the operator at the loading end strikes the last billet with a big hammer or with a dolly, whereupon the billets roll without fail. The long water-cooled rake bar is suspended from an overhead trolley.

Rounds that are to be heated to a temperature below 1650 F roll down an inclined hearth by gravity without being coaxed, if the inclination is sufficiently great. If rounds are to be heated to 2200 F, the slope of the hearth is usually made about 1 inch in 12 in. of length. From a scientific standpoint, the inclination should be smaller at the

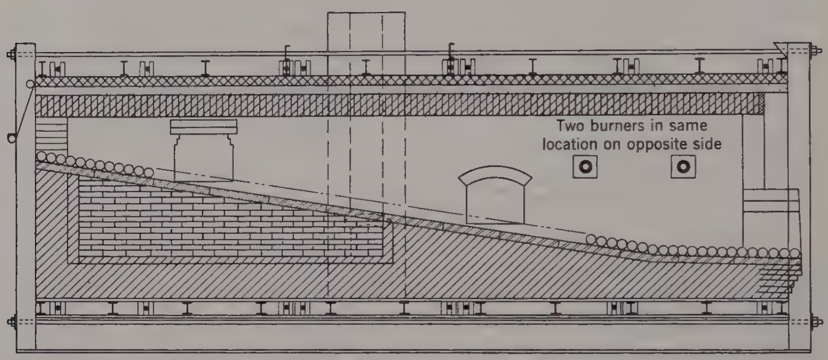

FIG. 220. Rolldown furnace for small rounds.

cold end and greater at the hot end, with a flat horizontal spot at the discharge end for stopping unruly billets. The flat spot is shown in Fig. 220, already referred to. In the 1920's, furnaces with inclined hearths were popular for rolling shells, gear blanks, and other round shapes (at 1600 F) down by gravity. Such furnaces required elaborate stops. Without these stops, the contents of the furnace landed on the floor all at once. These furnaces have been replaced by furnaces of other types. Filling an inclined hearth with cold rounds without damaging the furnace requires skill and care.

In mass production, shells have been rolled along horizontal furnace hearths if the furnace temperature did not exceed 1600 F. The rounds were prodded by cam-operated rods that came up through the hearth. This design also was abandoned on account of its limitations and on account of maintenance cost. The furnace was limited to rounds of one diameter only. It was disdainfully called a furnace "with fins and gills" under the hearth.

A number of rolldown furnaces for rounds are still in operation in the United States, but these furnaces are being replaced by furnaces of other types. In 1953 a German patent was granted on a tilting

rolldown furnace. It can have a horizontal hearth for loading, and the inclination of the hearth can, in regular operation, be adjusted to reduce to a minimum the labor of prying over. Design and operation should be less difficult than for tilting open-hearth furnaces.

Continuous Conveyors. Conveyors that travel continuously through furnaces may be broadly classified as (1) chain conveyors, (2) chain-link belts, (3) solid metal belts, and (4) belts of woven wire.

If a large number of identical or at least similar pieces are to be heated, continuous conveyors save labor and are, for that reason, installed whenever and wherever their labor-saving features pay off. However, conveyors have limitations which must be understood in order to avoid disappointment and financial loss.

All continuous conveyors must overcome friction forces. The conveyors slide on metallic supports against which the conveyors are pressed by their own weight and by the weight of the charge. The pull which a conveyor can overcome per inch of width is influenced by design, material of conveyor, furnace temperature, furnace atmosphere, and by method of loading.

Conveyors may stay in the furnace while going and while returning, or may return outside of the furnace.

Chain Conveyors and Link-Belt Conveyors. For many purposes, chains that remain practically cold are useful. They travel wholly outside of the furnace or else in grooves under the hearth. In either case they are equipped with attachments that reach into the furnace and carry the material to be heated. Figs. 221, 222, and 223 illustrate the principle. The grooves in which the chains travel (see Fig. 222) are often water-cooled. Cold chains are inexpensive, because they are standard, non-alloyed link chains with standard-attachment links to which carrier arms of any shape may be bolted. The carrier arms that project into the furnace are made of alloy steel, the composition of which is adapted to the furnace temperature. The carrier arms visible at the upper left of Fig. 222 present an unbroken line of support over each chain. They are suited to carrying elongated objects, such as automobile axles, through the furnace.

Chains may travel through a hot furnace and yet remain comparatively cold. If an extra-heavy conveyor chain with upward-pointing pyramid-shaped spikes serves for conveying thin washers or disks through a furnace, the disks attain final temperature while the chain is still black. On the return travel the chain passes through a water trough under the furnace. Four very small spots on the inner circumference of the washer remain black, but the temperature equalizes itself quickly when the disk or washer leaves the spike. The

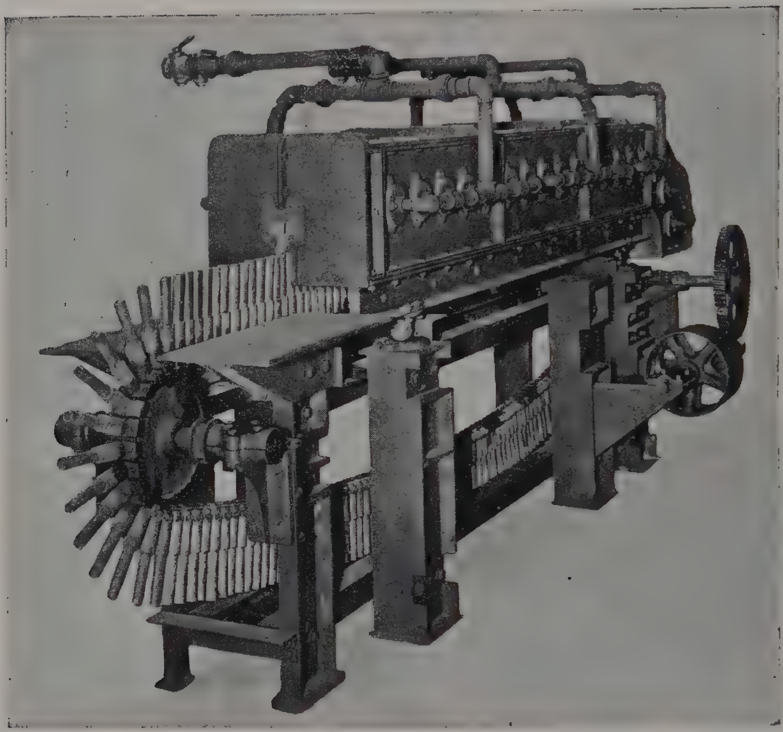

Fig. 221. Automatic furnace with chain outside of furnace. Note tubular attachments for carrying engine valves through furnace.

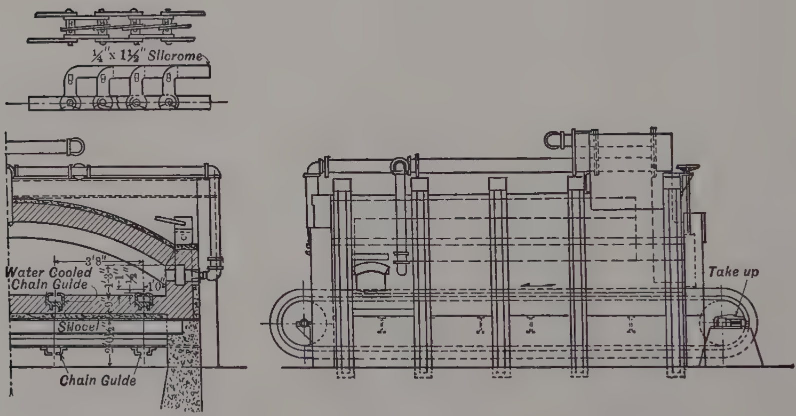

Fig. 222. Automatic furnace with chain in water-cooled guide.

pyramid shape of the spikes permits washers of different sizes to be heated without any change in the chain. This method of conveying a charge through a furnace exhibits very plainly the often-encountered conflict between labor economy and fuel economy.

Washers can be heated and transported through a furnace by means of a cold chain that never enters the furnace as shown in Fig. 224.

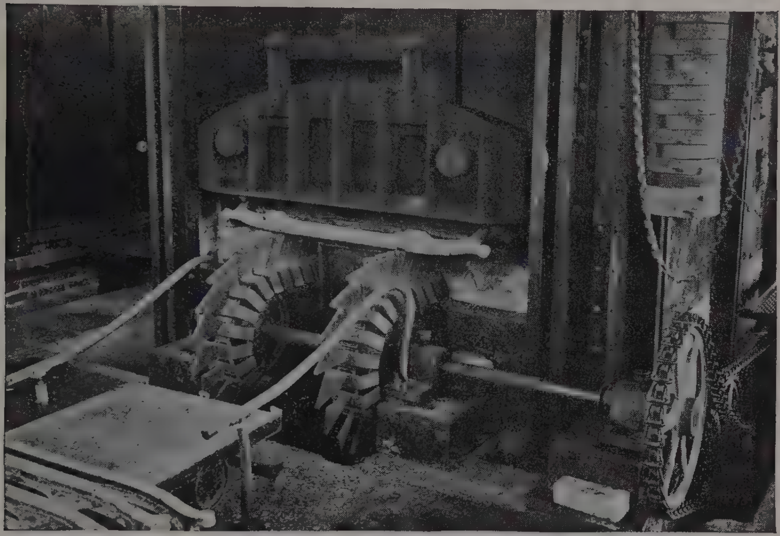

FIG. 223. Discharge end of chain-conveyor furnace for automobile axles. Note carrying fins attached to chain and bent pipes for conveying axles to truck.

The chain carries horizontal rods that rotate around their axes while passing through the furnace. The rods are made of a high-grade alloy steel. Rotation is necessary because non-revolving rods would bend. The washers are strung on the rods.

Chains that stay cold can be kept taut by screw adjustment. Cold chains traveling in grooves under the hearth should not be installed in furnaces in which scale can drop off the charge, because scale that finds its way into the grooves causes binding and jamming. Cold chains with hot carrier arms greatly simplify the work of loading and unloading, because the chain can extend beyond the furnace at either end. Unless the charge is to be heated in a protective atmosphere, the cold chain ranks high among the methods of automatic transportation through furnaces.

Hot chains require good engineering and careful operation. As may be expected, difficulties grow with temperature. If the load which a

chain of high-alloy steel can pull at 1200 F is called 100, then the permissible loads at higher temperatures are as follows:

Temperature, F	1300	1400	1500	1600	1700	1800	1900	2000
Load ratio, %	78	57	34	27	17.5	9.2	4.7	2.8

The values of this tabulation apply to a high-grade cast alloy with

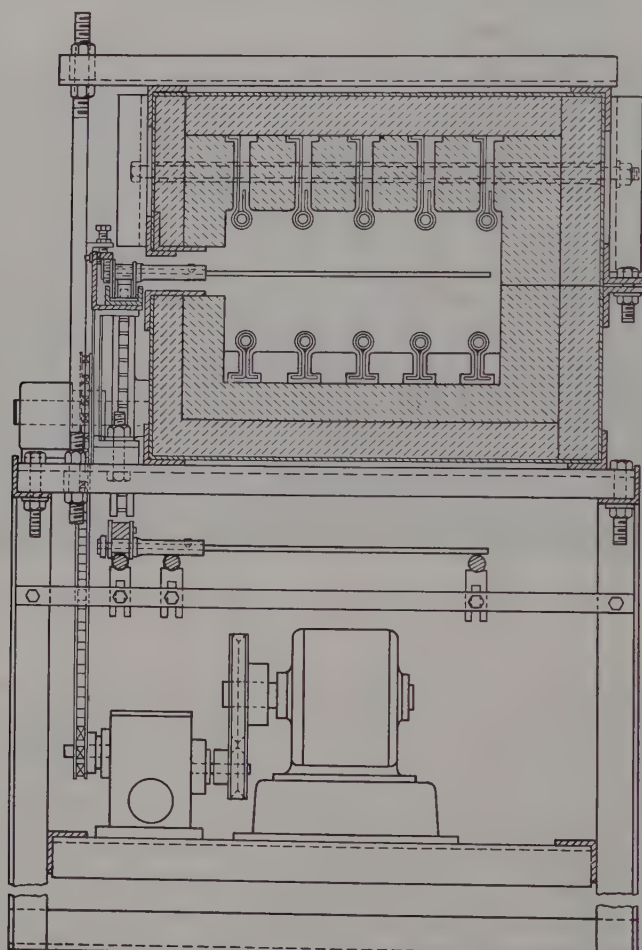

FIG. 224. Furnace with cold chain for heating washers on revolving rods.

great creep strength. Although they have to be modified for other alloys, they nevertheless prove that chains for high temperatures are too big and too expensive for most commercial applications.

Uniformity of temperature across the chain is very important, espe-

cially in wide furnaces. Lack of uniformity may be caused by incorrect firing or electric heating, but is more often caused by incorrect operation. If the cold charge is persistently placed on one and the same half of the chain, the bare part expands more and the cold half exerts the whole pull. At first thought, this distribution of force may appear to be a corrective measure, because the cold chain is stronger than the hot section. However, the "cold half" reaches furnace temperature near the discharge end, where the pull is greatest, and is stretched out of shape at the hot end. In wide furnaces the difference in expansion can amount to ⅜ in. or even more.

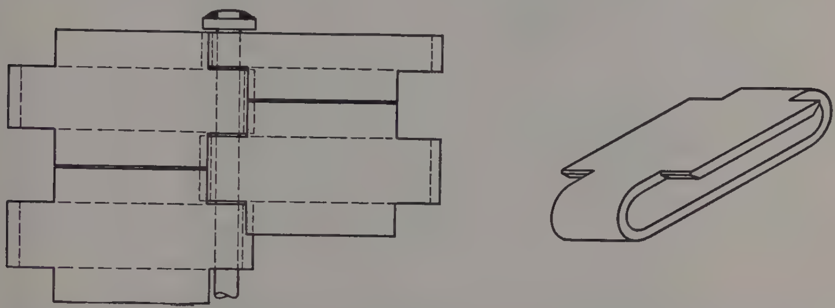

Fig. 225. Chain links with small bending stress. Courtesy of Electro-Alloys Division, A. B. S. Co.

The coefficient of friction between conveyor (link chain or belt) and the supporting guide beam is of importance because the force against which the chain or the belt works is proportional to the coefficient of friction. If the sliding surfaces are metallically clean, the coefficient ranges between 0.4 and 0.55, the lower value applying to higher temperatures. The amount of deposited graphite also affects the value of the coefficient of friction. Scale, whether oxide or sulphide, increases the coefficient to 0.6 or slightly higher.

Stress in the conveyor, and temperature, determine the rate of creep for a given chain material. The tensile stress in the body of a link, if evenly distributed, equals weight of (charge + chain) times coefficient of friction divided by the smallest cross-sectional area of the link. A link with reasonably uniform cross section and a combination of such links are illustrated in Fig. 225. The length of the chain between centers of pulleys enters into the stress equation because it affects not only the weight of the charge but also the weight of the chain, both of which determine the frictional force against which the chain must pull. All makers of conveyor belts have developed tables or curves by means of which the correct size of conveyor can be found.

Fig. 226 is typical of such curves. In many designs, if a chain link works near (or beyond) its pulling capacity, the connecting pins fail

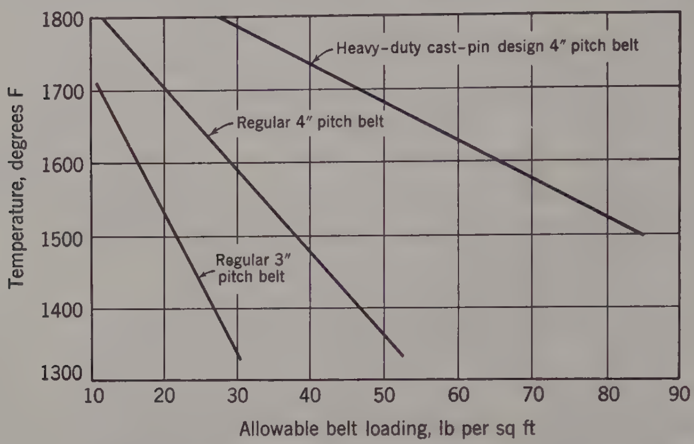

FIG. 226. Typical temperature-load curve for link chains. Allowable belt loading, bearing centers 22′–0″, concentrated loading (assuming that 40–50% of the belt is evenly loaded). Courtesy of Electro-Alloys Division, A. B. S. Co.

before the links fail. The pins transmit force supposedly by shear, but actually they bend ("crankshaft"). Fig. 227 illustrates what happens. For extremely heavy duty (high temperature, heavy pull)

FIG. 227. Failure of chain by bending of pins. Courtesy of Electro-Alloys Division, A. B. S. Co.

the teeth of the driving drum do not take hold of the pins, but act on hubs that are cast integral with the links. In this stronger design,

which is shown in Fig. 228, the curved part of each link is the weakest section.

The driving drums are so designed that the links do not touch the drum between the teeth, in order to prevent bending stresses. The material of the chain must be suited to the temperature in which it is to serve and to the stress to which it will be subjected. Informa-

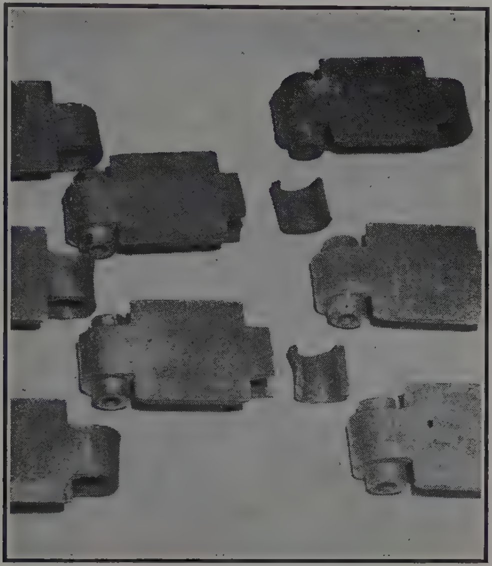

Fig. 228. Heavy-duty chain links transmit very great forces and fail by tearing of links. Courtesy of Electro-Alloys Division, A. B. S. Co.

tion on creep strength of various alloys is given in Volume I. For the most commonly used furnace temperature of 1600 F, chain material contains 35 to 40 per cent nickel and 15 to 17 per cent chromium.

Link chains that convey small objects are designed to offer a solid, unbroken surface at the top. They are equipped with traveling side guards. Both features are clearly shown in Fig. 229. Incidentally, this picture shows the shape of the driving drum and of the idler drum. The idler drum may have teeth, but can get along without them. When coming up around the idler drum, the chain is subjected to very little tension and straight links will not be bent out of shape. If the idler drum is equipped with teeth, subdivision of the drum into several short drums is advisable. They are loose on the axle. The chain links slide on beams of alloy steel. If elongated objects of unvarying size are to be transported through a furnace, the chains can be of the open type. Such a chain is shown in Fig. 230.

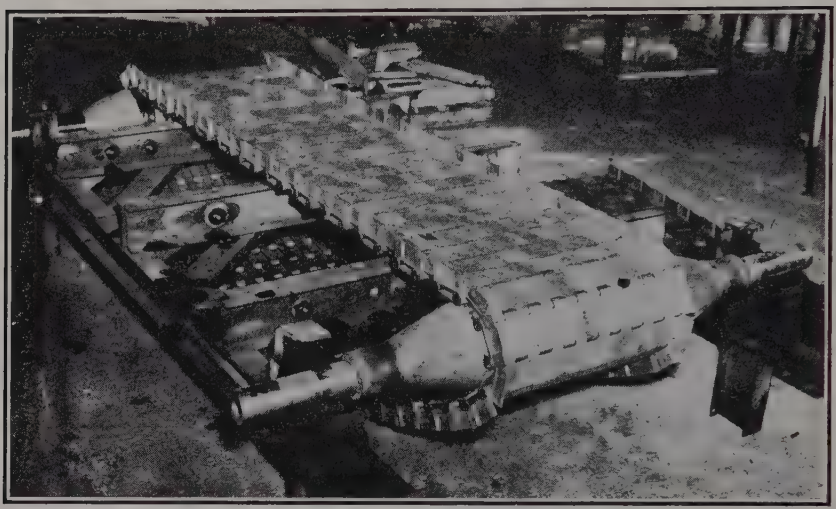

Fig. 229. Assembly of link belt for furnace. Courtesy of Electro-Alloys Division, A. B. S. Co.

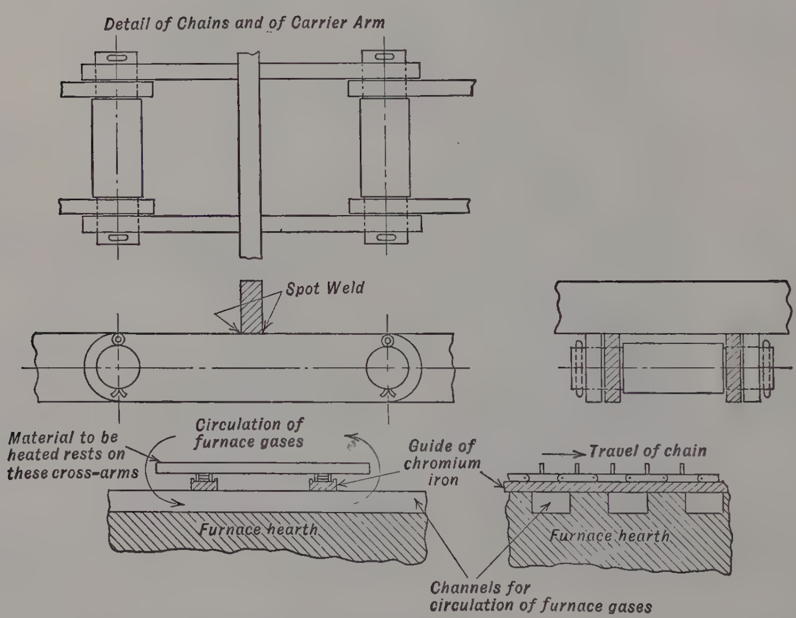

Fig. 230. Alloy chain for traveling through hot furnace. Note that carrier arms are welded to both strands of the chain.

An alloy link-chain belt for light work weighs about 17 lb per sq ft. Tension in the link chain is maintained by a spring located outside the furnace that acts on the idler drum, or by a weight that acts through a bell crank.

Solid Metal and Woven-Wire Belts. For furnace transportation of light material, metallic belts are well suited. Attempts were made to use an endless strip of alloy steel, but strips belts had a short life,

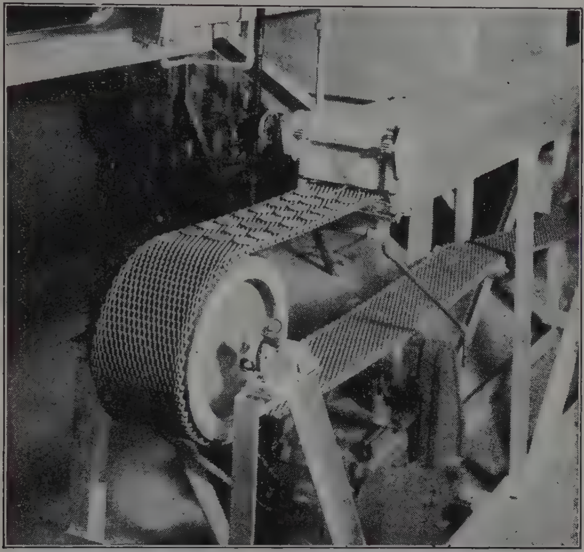

Fig. 231. Automatic furnace with wire-mesh belt.

because tears at the edges soon progressed through the whole width. Belts woven of stainless-steel wire proved to be more serviceable; many such belts are now in operation. Size of wire and closeness of weave are selected to suit size, weight, and shape of the charge. The number of different weaves is bewildering.

In Fig. 231 a woven-wire conveyor belt projects out of the furnace. In the majority of modern installations the belt does not travel out into the open atmosphere, but stays in the furnace at all times. Wire-mesh belts are truly belts. The driving pulleys have no teeth and the rules of machine design can be applied. If the usual contact angle of 180 degrees does not produce enough friction for pulling the load, a belt tightener is installed, which, in the practice of woven belts, is called a snubber. Many different designs of snubbers are in use, varying with the requirements. A very common design is crudely sketched in Fig. 232.

In belt drives, the force transmitted by the driving pulley is the difference of forces on the tight side and on the loose side. The latter tension is transmitted around the idler pulley and increases the tension on the tight side. The wires do not lie in the line of pull but at an angle, so that the force in the wire exceeds the useful force in the line of pull. And, finally, the wires are wrought material which, in heat-resisting alloys, has a lower creep strength than cast material (see Volume I). In spite of these three hindrances the woven belt is a success if properly selected and applied.

A fairly definite relation exists between diameter of wire, type of weave, and minimum safe diameter of pulley. If the diameter of the pulley is too small, the wires are bent too much and the life of the

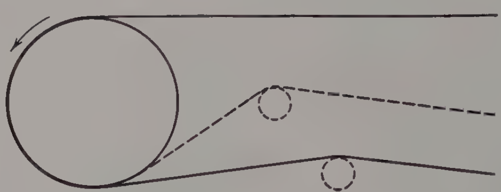

FIG. 232. Snubber (tightener) for furnace belts.

belt is shortened. Of the rules for determining the minimum safe diameter there are many. One maker uses the following rule of thumb: Safe diameter of pulley (inches) equals 170 divided by the number of spirals per foot of length of belt. Thus, if the belt contains 17 spirals per foot of length, a safe diameter of pulley is $170/17 = 10$ in. Other makers use similar rules. The design of the pulleys is the same as it is for the idler pulleys over which chain-link belts pass.

If the charge is of such a shape that the pieces may roll off the belt, furnace belts of all types are equipped with side guards. These guards may be solid or woven; in either case, they consist of short pieces that overlap like shingles, as shown in Fig. 229.

Furnace belts of all types are supported by rails and beams of heat-resisting steel. The makers of furnace chains and belts pay much attention to the design and the material of the supports, because sagging of the supports results in failure of chains and belts and even in lawsuits for incorrect design and material of belts.

In the selection and in the installation of wire-mesh belts the experience of the makers carries much weight. It is, of course, impossible to crowd their experience into a small section of this chapter, but it is possible to convey a general idea of load-carrying capacity as a func-

tion of several variables. For that purpose, Figs. 233 and 234, as well as Tables XV and XVI, are offered. The tables teach that the load which can be carried under otherwise equal conditions is roughly

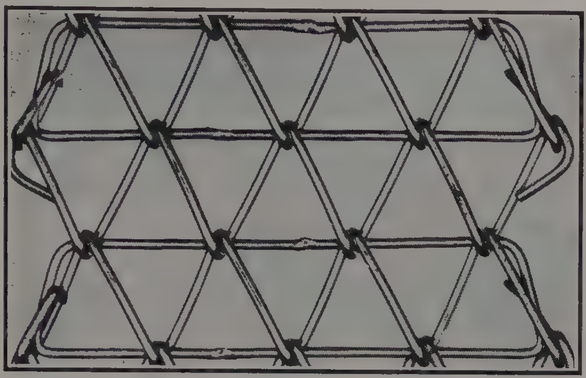

FIG. 233. Light-duty woven-wire belt, 1 in. between centers of reinforcing rods. Courtesy of Wickwire Spencer Division of C. F. & I. Co.

proportional to the weight of the belt per square foot. The influences of furnace temperature and of length of belt also show up clearly. At 2150 F and with a belt length (between pulleys) of 24 ft the useful

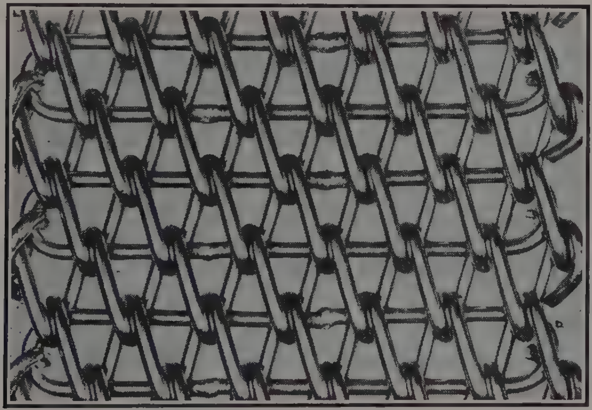

FIG. 234. Extra-heavy-duty woven-wire belt, ¾ in. between centers of reinforcing rods. Courtesy of Wickwire Spencer Division of C. F. & I. Co.

load would be zero. The examples shown in the illustrations and tables represent light-duty belts and very heavy-duty belts. Between these extremes many weaves for intermediate duties are on the market.

The characteristic properties of woven belts originating with other makers are similar to those given in Tables XV and XVI.

The use of protective atmospheres is the main reason for keeping chains of all types always in the furnace. Loading and unloading of

TABLE XV

SUGGESTED OPERATING DATA

1½-in. mesh, No. 9 gage belt, weight 2.00 lb per sq ft

Temperature	Maximum Tension at Zone of Highest Temperature, lb/ft width	Working Load When Distance from Charge-End Pulley to End of Heating Chamber Is 6 Ft, Lb/Sq Ft	9 Ft	12 Ft	Suggested Alloys		
1200° F	1000	72	47	34	18Cr-8Ni	14Cr	17Cr
1300	900	72	47	34	18Cr-8Ni	14Cr	17Cr
1400	600	72	47	34	18Cr-8Ni	14Cr	17Cr
1500	300	69	45	33	18Cr-8Ni	25Cr-12Ni	
1600° F	230	52	34	25	25Cr-12Ni		
1700	170	38	25	18	25Cr-12Ni	25Cr-20Ni	
1800	130	28	17	13	25Cr-20Ni	Inconel	34Ni-19Cr
1900	100	21	13	9	25Cr-20Ni	Inconel	34Ni-19Cr
2000° F	80	17	10	7	25Cr-20Ni	80Ni-20Cr	34Ni-19Cr
2050	71	14	9	6	25Cr-20Ni	80Ni-20Cr	34Ni-19Cr
2100	64	13	8	5	80Ni-20Cr		

hot chains causes some inconvenience. In hardening furnaces unloading is simple. The pieces that form the charge tumble over the edge of the chain into a chute that leads down into the quenching bath. Vapors arising from the bath are usually removed by an eductor. The

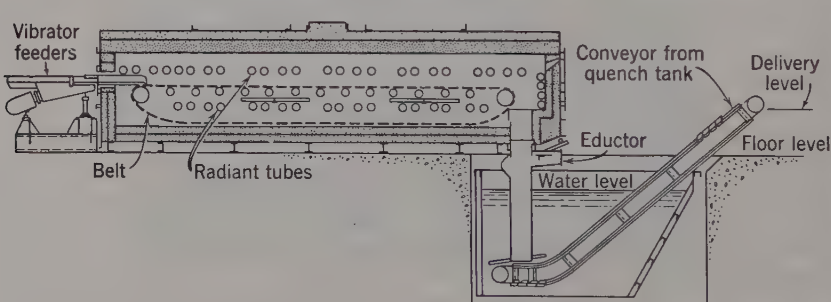

FIG. 235. Method of loading and unloading hot furnace belt.

arrangement is diagrammatically illustrated by Fig. 235. In that illustration, as in several others, the circles that appear in pairs indicate radiant tubes of the hairpin type. The single circles indicate

chain-supporting rollers. If the individual pieces are heavy, the delivery chute is inclined, for the purpose of reducing the impact at the bottom of the quenching tank. In annealing furnaces or draw furnaces the use of chains is comparatively rare, especially if the furnaces carry a protective atmosphere. The chain may be split into two chains. The furnace chain then unloads onto the lower-lying

TABLE XVI

SUGGESTED OPERATING DATA

¾-in. mesh, No. 6 gage belt, weight 7.00 lb per sq ft

Temperature	Maximum Tension at Zone of Highest Temperature, lb/ft width	Working Load When Distance from Charge-End Pulley to End of Heating Chamber Is 6 Ft	9 Ft	12 Ft	Suggested Alloys		
		Lb/Sq Ft					
1200° F	3400	240	150	110	18Cr-8Ni	14Cr	17Cr
1300	2800	240	150	110	18Cr-8Ni	14Cr	17Cr
1400	1700	240	150	110	18Cr-8Ni	14Cr	17Cr
1500	1100	240	150	110	18Cr-8Ni	25Cr-12Ni	
1600° F	920	210	138	101	25Cr-12Ni		
1700	670	151	98	71	25Cr-12Ni	25Cr-20Ni	
1800	490	108	69	50	25Cr-20Ni	Inconel	34Ni-19Cr
1900	350	75	47	33	25Cr-20Ni	Inconel	34Ni-19Cr
2000° F	280	58	36	25	25Cr-20Ni	80Ni-20Cr	34Ni-19Cr
2050	230	46	28	19	25Cr-20Ni	80Ni-20Cr	34Ni-19Cr
2100	220	44	26	18	80Ni-20Cr		

chain in the cooling chamber. At the loading end various devices are in use for minimizing the loss of protective atmosphere. Among them is the shaker feeder or vibratory feeder, which is indicated in Fig. 235, referred to above.

Roller Conveyors. For a number of problems in furnace transportation the roller hearth offers a good solution. In its simplest form it consists of a number of revolving rods which are driven from a shaft outside the furnace. Fig. 236 illustrates such a design. In this particular application the rollers are made of a heat-resisting alloy which can assume furnace temperature without being damaged. The method of driving the rollers from outside the furnace by means of worm gears and a long screw is clearly shown in the illustration. The rollers must revolve fast enough to prevent any noticeable temperature difference between top and bottom; otherwise, warping is inevitable. The rollers sag if they stand still at furnace temperature.

Roller hearths have been installed for a wide range of furnace temperatures, from 1200 F to 2200 F. Strangely enough, among the

earliest installations were refractory rollers for 2200 F. A string of firebrick sleeves or disks were clamped between fixed collars and springs on water-cooled shafts. The rollers lay between firebrick spacers or piers and had only their top segments exposed to the high heat. In any one revolution each spot of the surface of the roller was subjected

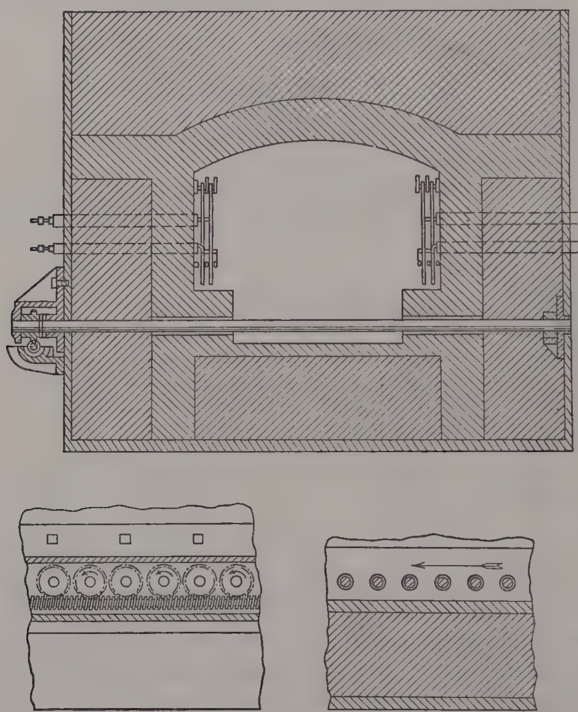

Fig. 236. Roller conveyor in electrically heated furnace. The rollers are made of heat-resisting material.

to alternate heating and cooling. And, to increase the destructive action, the temperature gradient between outer and inner surfaces of the refractory sleeves was excessively great. The rollers transported plates; it was impossible to keep the rollers covered by plates at all times. The rollers cracked and crumbled at the hot end.

In 1947 a British engineer attempted to overcome the difficulties by interposing metallic disks between the refractory disks. Alternation between refractory and plates of metal was long ago known to be a means for preventing the spalling of magnesite bricks in open-hearth furnaces. The underlying principle is that heat conduction through the metallic disks reduces the heat gradient in the refractory material

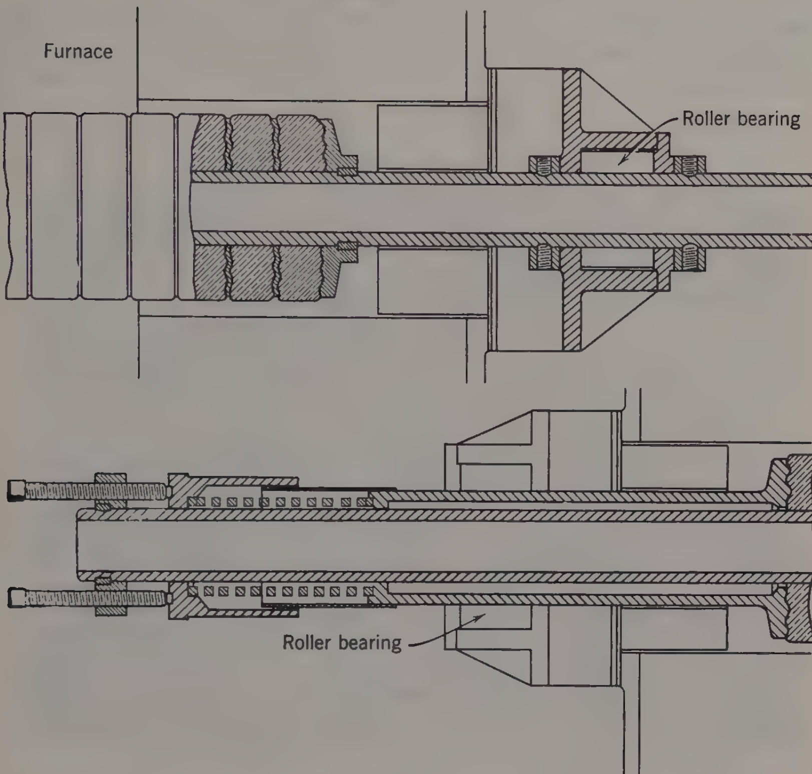

FIG. 237. Refractory furnace roller with provision to prevent spalling.

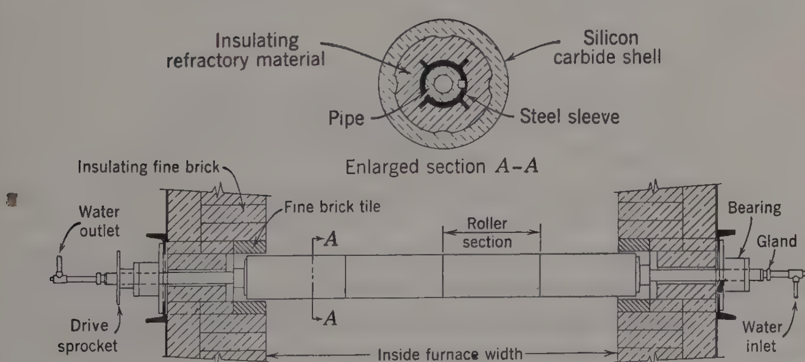

FIG. 238. Furnace roller with shell of silicon carbide. Courtesy of Gas Machinery Co.

and thereby prevents spalling. Rollers protected in this way are illustrated in Fig. 237. The tubular shaft is water-cooled and is held in a fixed axial position at one end. At the other end, an adjustable

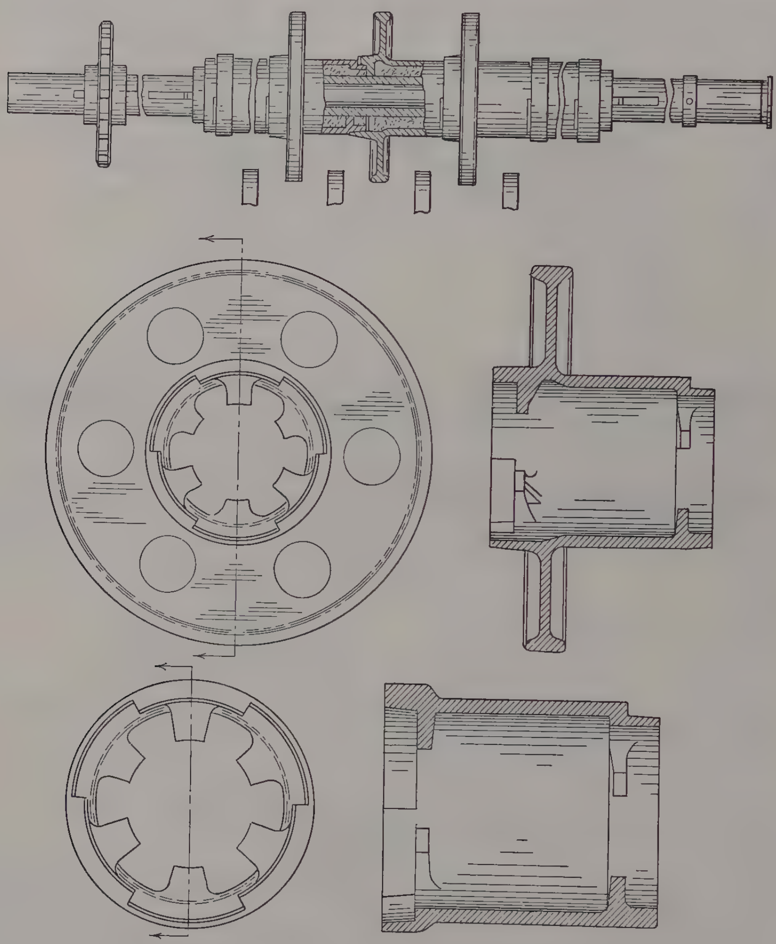

FIG. 239. Roller with hot disks, insulated from water-cooled shaft.

compression spring puts the shaft into tension and the rollers into compression. The corrugated metallic disks touch the shaft in small spots only. The design is intended to serve in temperatures up to 2200 F.

Silicon carbide withstands very high temperatures, unless it comes in contact with molten iron or molten scale. A conveyor roller of silicon carbide is illustrated in Fig. 238. This roller, which was intro-

duced about 1946, consists of three different parts: (1) a load-bearing water-cooled shaft, to which a ribbed steel shell is keyed; (2) an outer sleeve of silicon carbide; and (3) a refractory cement that firmly unites parts 1 and 2. Rollers of this type are used mainly for transporting stainless steel (at 2100 F), since such steel does not form enough scale to injure the rollers.

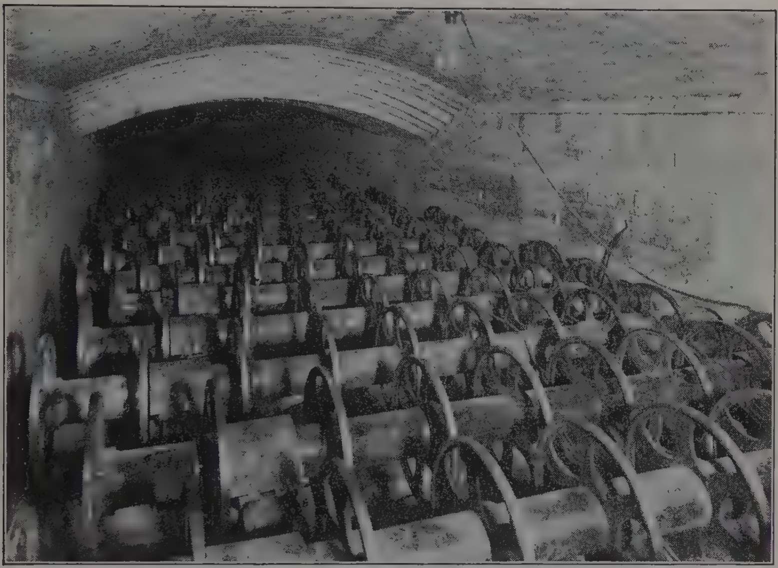

FIG. 240. Interior of furnace with disk shafts resting on alloy roller.

In the days when sheets were rolled on hand mills, many sheets were annealed while traveling through a furnace on rollers. The slightest irregularity in the motion of successive rollers scratched the sheets, unless they traveled on "wasters," which were dispensable seconds. The heat imparted to the wasters or rider sheets was, of course, lost, and so was the heat that was transmitted to the water-cooled drive shafts. In order to reduce the latter heat loss, rollers with insulation were developed; one such design is illustrated by Fig. 239. The disks form, by their extended hubs, an outer shell, between which and the shaft a fibrous (not powdery) insulating material is packed. The hubs touch the cold shaft over a portion only of the circumference. Several modifications of this design appeared on the market, including air-cooled rollers. The roofs of some furnaces were made removable, bung-top type, for easy access in case of repairs.

The torque that is needed to turn the rollers is very small. The rollers act more as axles than as shafts. If the rollers can be sup-

ported in the furnace, the drive shaft may have a very small diameter and transmit a negligible amount of heat to the outside. A design embodying this principle is illustrated in Figs. 240 and 241. The shafts, made of alloy steel, rest on rollers that are likewise made of alloy steel. This arrangement was very popular about 1940. The

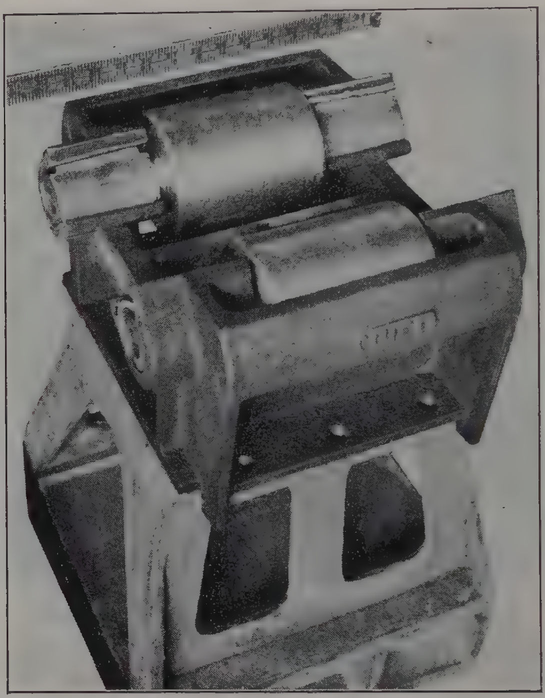

FIG. 241. Alloy roller supports for shafts of Fig. 240.

alloy must be adapted to the furnace temperature; it must have a sufficiently great creep strength. From time to time, graphite-coated wasters or trays are run through the furnace for the purpose of dropping graphite onto the bearings of the supporting rollers.

Improvement in the art of making alloy castings has rendered possible the design of rollers shown in Fig. 242. The main body is a centrifugally cast hollow cylinder to which alloy necks are welded. From Volume I it is known that alloy castings have a higher creep strength than is exhibited by wrought material. The thin wall of the roller offers resistance to axial flow of heat. The rollers are usually mounted in self aligning ball-bearing pillow blocks, as shown in Fig. 243, which illustrates part of an electrically heated furnace.

The non-driven ends of the rollers are capped so as to reduce the leakage of protective gas. The rollers, which are axially fixed at the driven end, expand axially as well as radially. For taking care of radial expansion the journals are made about $\frac{1}{100}$ in. smaller than the races of the bearings. Fig. 243 also shows the refractory block through which the roller can be removed in case of repairs.

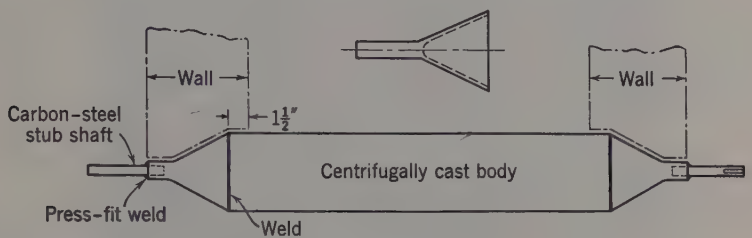

FIG. 242. Thin-walled furnace roller.

Conveyor rollers that rotate while under load and while exposed to furnace temperature are commonly designed for a creep value of 1 per cent in 10,000 hours. Values of creep strength for various alloys are given in Volume I. Rollers do not creep as much as chains, because each element is alternately exposed to tension and to com-

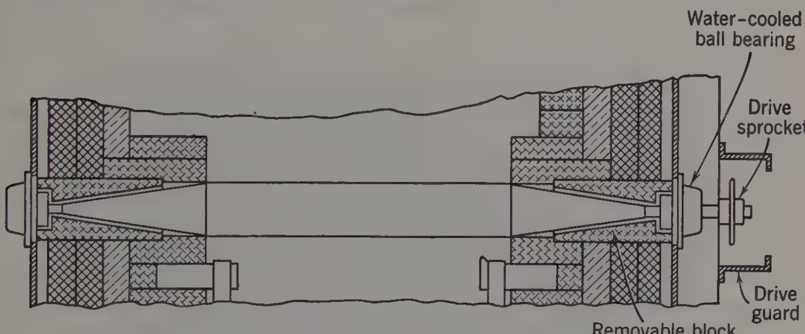

FIG. 243. Mounting of thin-walled furnace roller.

pression. Conveyor rollers need not always rotate in the same direction. If the charge consists of coils of strip, it is occasionally advantageous to operate the rollers in "Pilgerschritt" (pilgrims' step, five steps forward followed by three steps backward). Alloy rollers are in use for temperatures up to 2050 F.

Rigid, elongated material without projections, such as bars or pipes, is sometimes laid directly on the rollers. All other material is always

laid on light but rigid trays of the type that is illustrated by Fig. 244. If the pieces of the charge are so small that they would drop through the openings in the trays, the charge is placed in light baskets or on

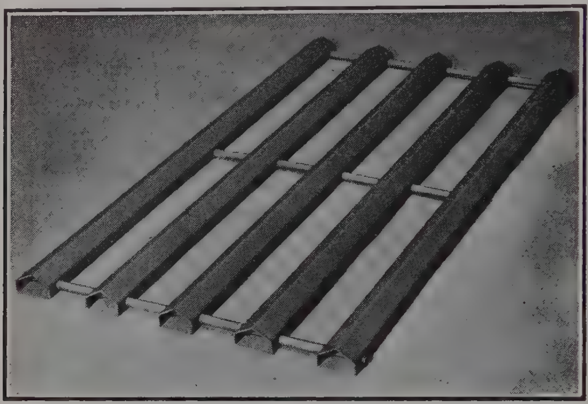

FIG. 244. Furnace-roller tray for large-sized material.

wire mesh on top of the trays, as shown in Fig. 245. For many purposes it is advisable to subdivide the string of rollers into sections for the purpose of entering and discharging trays quickly. The high-speed sections may continually travel at a higher speed than the rest

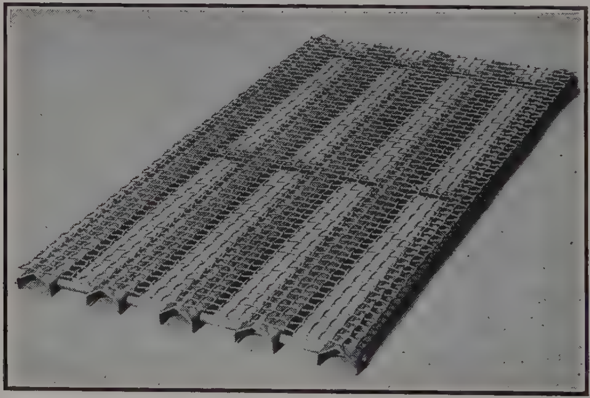

FIG. 245. Furnace-roller tray for small-sized material.

of the rollers. Under these conditions, friction occurs between trays and rollers. Or the high-speed sections may be operated at the high speed intermittently. Speeding up of rollers and operation of doors has been accomplished by electric eyes.

The equipment for turning the rollers is invariably located on the outside of the furnace. An example of a drive by means of worms and worm wheels is given in Fig. 236. Bevel gears may be substituted for worm gears, but the standard drive consists of an endless chain which engages a sprocket gear at the end of each roller.

Car-Type Conveyors. The car-bottom furnace has so many advantages with regard to the ease of loading and unloading heavy and bulky objects that its use has suggested itself to engineers for the continuous conveying of such objects through furnaces. Fig. 246 illustrates the principle of the continuous car-type furnace. The car-

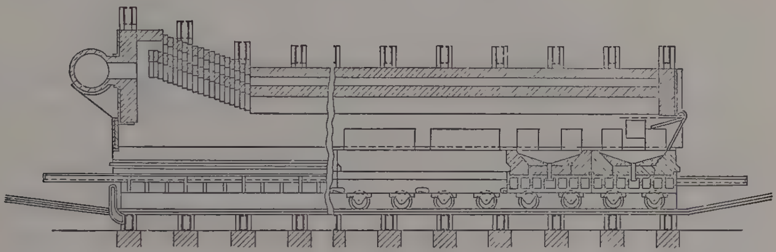

FIG. 246. Continuous furnace with car-type conveyor.

bottom conveyor has been developed to a high state of perfection in furnaces for the ceramic industry; they are called tunnel kilns. In the metal industry, car-type conveyors are seldom encountered. Before the general adoption of the strip-sheet mill, they served for annealing piles of sheets and of tinplate. During the Second World War they carried heavy, welded bomb bodies through furnaces. In 1953 their use was tentatively adopted for carrying rounds (that are to be converted into seamless tubes) through the furnace.

Continuous furnaces of the car type are best suited to a process in which the charge is first heated and is then cooled in the furnace. In this process the incoming charge is preheated by the outgoing products of combustion, and the outgoing charge preheats the combustion air. Another prerequisite for commercial success is that the charge be heavy and of practically constant weight. These conditions are found but seldom in the metal industry. They existed before the general adoption of the strip mill. No scale can be formed when ceramic goods are heated to very high temperatures. In the heating of steel, scale and slag can jam the conveying equipment. Car-type conveyors cannot successfully be equipped with sand seals. The under side of the car is protected against radiation by tongue-and-groove brickwork.

Reciprocating Hearths (Shaker Hearths). Material can be transported into and through a furnace on reciprocating hearths by utilizing inertia and friction. Two closely related methods are available. In one method, the hearth is moved forward with an acceleration that is not great enough to produce relative motion between charge and hearth. When the intended velocity has been reached, the hearth is stopped suddenly by a bumper; the charge slides forward. The

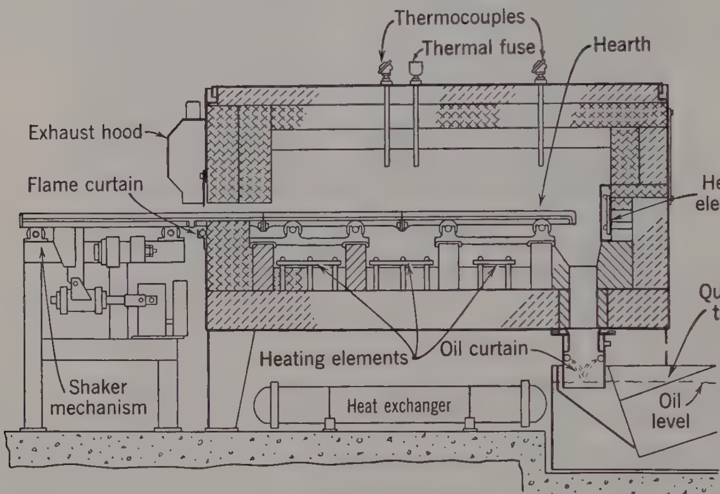

Fig. 247. Furnace with shaker hearth. Courtesy of Westinghouse Electric Co.

hearth is then retracted at a slow speed. In the second method the hearth is moved forward as before explained and is then pulled back with an acceleration that is great at first and then diminishes.

The shaker hearth is well suited to the heating of small articles, such as knife blades, flat springs, washers, etc. The shaker hearth is not adapted to the heating of objects that roll, such as balls, cylinders, or cones. Fig. 247 is a schematic drawing of an electrically heated furnace of the shaker-hearth type. The first furnaces with shaker hearths were gasfired, and gas firing continues to be extensively used. In the furnace of the illustration the charge is placed on the shaking loading platform and is finally dropped into a quenching bath. The mechanism for producing a correct shaking motion may be operated mechanically (through an electric motor), hydraulically, or pneumatically. Its description does not belong in this book.

A shaker hearth moves as one piece and yet it must be free to expand differentially between hot end and cold end. This requirement is met

by making the hearth in sections and by bolting the sections together. The nuts are secured against being loosened by the vibration.

Vibrating Hearths. A vibrating hearth has an extremely small inclination, which is so small that only balls and cylinders move along the hearth by gravity. But if the hearth is subjected to vibration of sufficient intensity, even flat pieces move along the hearth, and they move at a constant velocity. Fig. 248 explains the action. Each piece of the charge is kicked away at right angles to the hearth and then falls back vertically. The rate of forward motion is increased by greater inclination of the hearth and by more intense vibration. It is self-evident that vibrating hearths will vibrate only when the hearth material is capable of transmitting elastic vibrations. The vibrator is a good feeder for chain belts.

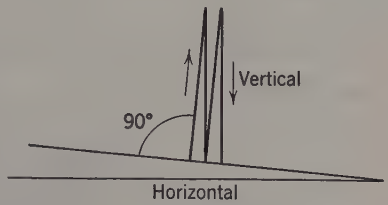

FIG. 248. Explanatory diagram of vibratory feeder.

Rocker-Bar Furnaces (Walking-Beam Furnaces). Next to chains, the method of transporting material through furnaces by means of rocker bars has appealed most strongly to inventors and designers. The principle underlying this method is illustrated by the diagram, Fig. 249. In this illustration, 1 denotes a fixed hearth, while 2 represents a beam which makes any one of the motions indicated by the paths A, B, C. By any of these motions, material resting on the hearth is picked up, is carried forward a certain distance, and is then deposited farther along the hearth, while the rocker bar, 2, disappears below the hearth and returns to its original position. Instead of the combination (rocker bar plus fixed hearth), two sets of rocker bars can be installed: one set going up and forward while the other set goes down and backward. Transportation is then twice as fast. What has been said above with regard to the applicability of chains for

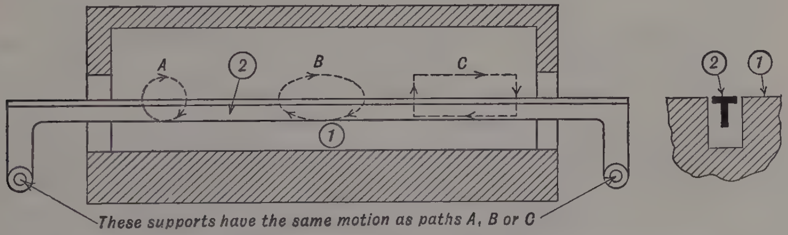

FIG. 249. Diagram illustrating action of rocker-bar conveyor.

conveying purposes as a function of furnace temperature can be repeated for rocker bars. As long as the furnace temperature is low so that but little scale is formed, the rocker bar, or walking beam, which cuts up the continuity of the hearth very much, is well suited to transporting materials through a furnace; for furnaces in which thick and loose scale is formed the rocker-bar furnace cannot be recommended, since the scale drops into the slots of the walking beams and causes endless trouble unless original design and vigilant maintenance are excellent.

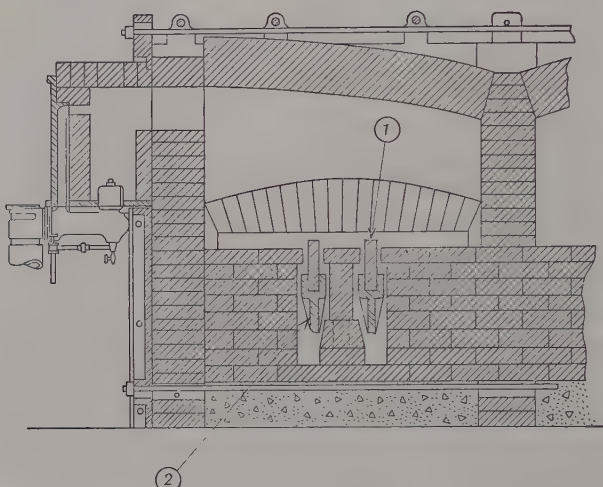

FIG. 250. Cross section through furnace of the rocker-bar type.

Rocker-bar transportation through furnaces poses a dilemma. There should be *ample space* between rocker bars and hearth so as to avoid jamming by scale and by warped walking beams. There should be *very little, if any, space* between rocker bars and hearth so as to avoid undesirable flow of furnace gases. Industrial furnaces are operated with a slight pressure at hearth level, in consequence of which pressure hot furnace gases are forced into the mechanism that operates the rocker bars. The result is that even the best design of rocker-bar furnace is a compromise. This type of furnace should never be used for temperatures above 1750 F, although one installation was made for a temperature of 1850 F with very indifferent success.

If a rocker-bar furnace is to be free from trouble, the above-mentioned facts must be very carefully taken into account not only by the designer and the builder of the furnace but also by the man who operates it. A cross section through a furnace whose designer tried to

take care of some of these objections is shown in Fig. 250. Refractory members, 1, are held rather rigidly in metallic beams, 2. Brick edges of the hearth project sufficiently far to protect the underlying metallic beams against too much direct radiation from the furnace interior. The beams, 2, are moved by eccentrics located at both ends and outside the furnace. There is sufficient space below the beam

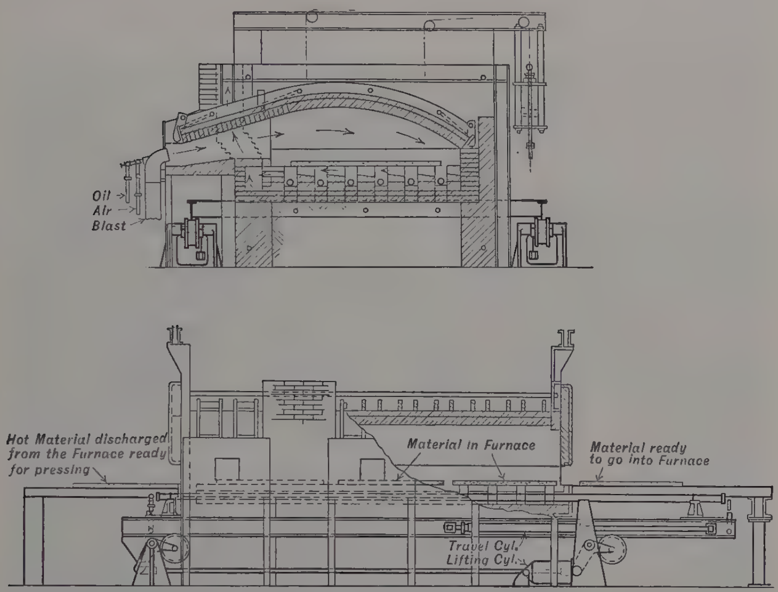

FIG. 251. Rocker-bar furnace for heating plates. The rocker bars travel through a rectangular path and are operated by two hydraulic cylinders.

ends to allow some accumulation of scale, and yet there is not much room left for circulation of air or of products of combustion between the space under the beams and the heating chamber.

A rocker-bar furnace which is used for heating plates for press work is shown in Fig. 251. In this design attention was paid to overcoming most of the difficulties which were cited. The motion of the rocker bars corresponds to path C of Fig. 249. The rocker bars consist of water-cooled pipes which drop into grooves between piers on the hearth. The products of combustion heat the plates from the top and from the bottom. Furnaces of this type have been built in lengths of 12 to 25 ft.

A good idea of the appearance of the mechanism connected with a rocker-bar furnace may be gained from Fig. 252, which is a view

of the charging end of a furnace for heating axles. The wide-flanged I beams which carry the moving hearth are plainly visible.

Before the general adoption of the strip-sheet mill, walking beams of alloy steel, and with refractory tops, were used a great deal for sheet normalizing. The development of roller hearths, of centrifugally cast rollers of an alloy with high creep strength, of silicon-carbide rollers, and the use of protective atmospheres have greatly reduced the field of usefulness of the furnace with walking beams.

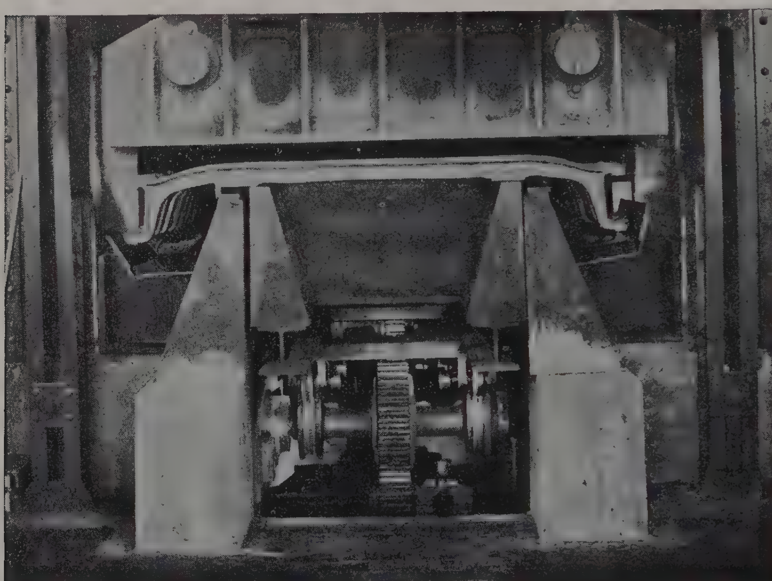

Fig. 252. Charging end of a rocker-bar furnace for heating axles.

Overhead Conveyors. Many objects lend themselves to being carried in suspension through a furnace. For such purposes overhead conveyors either of the double-rail type or else of the monorail type are used. It is immediately evident that overhead conveying is best suited to comparatively light objects and to furnace temperatures of 1600 F or lower. Since 1951, overhead conveying serves furnaces in which objects of medium weight are suspended at 2300 F.

One difficulty that is encountered in overhead conveying is keeping the slot in the roof tight, or at least almost tight. Furnace pressure is greatest immediately under the roof, and gases are shot out of any opening in the roof. Fig. 253 illustrates one of the methods by which the escape of hot products of combustion is reduced to a minimum. Flexible sheets press against vertical I-shaped plates. The curved

flanges of the I keep dirt from falling into the furnace. The chain located immediately below the wheels bends in a horizontal plane and passes around pulleys with vertical shafts. By this arrangement, heat-treated objects can be removed from the hooks conveniently and untreated ones can be hung. The binding and the support of the overhanging part of the roof must be very rigid. This part is not shown in Fig. 253 but is very well demonstrated in Fig. 254, which shows the top of another furnace for transporting suspended objects and which reveals the diagonal suspension of the overhanging roof from the binding.

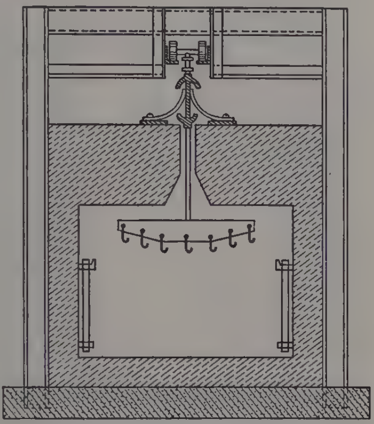

FIG. 253. Suspension conveyor with overhead rails.

Monorail conveyors are much used in continuous japanning ovens.

The shapes of the attachments by means of which the individual pieces of the charge are suspended vary greatly with the shapes of the suspended objects and with the ingenuity

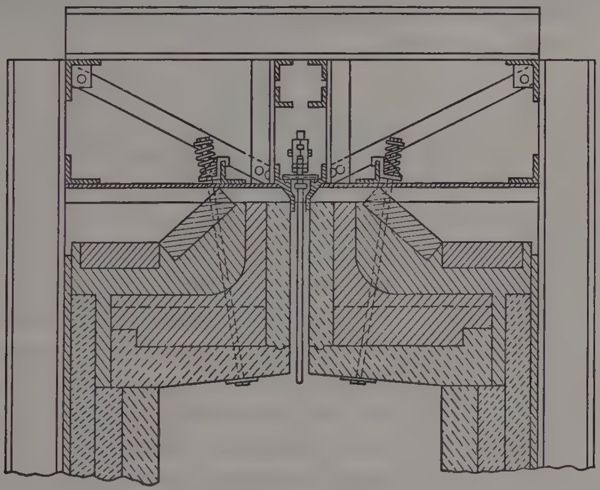

FIG. 254. Bracing of top of furnace designed for a suspension conveyor.

of the draftsman. Their number is so great that they are not illustrated here with the exception of one very unusual and extremely ingenious method of suspension. Fig. 255 shows the entrance of sus-

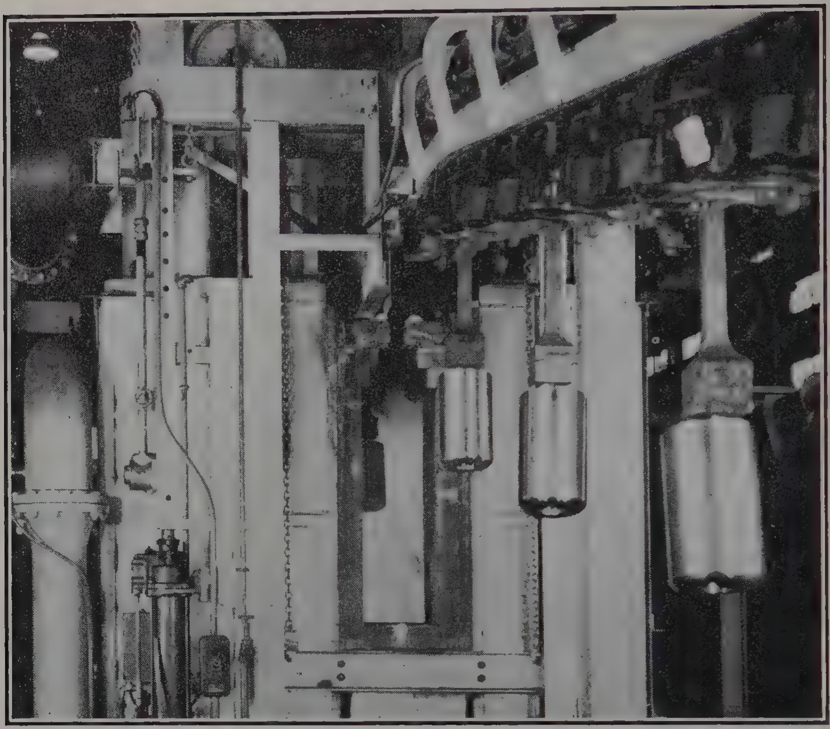

FIG. 255. Overhead conveying of "handled" billets. Courtesy of National Tube Co.

pended billets or slugs into a high-temperature furnace (2300 F), and Fig. 256 shows the handle that fits into the depending link of the conveyor. The billets have small holes and are heated for extrusion to become tubes. On account of the hole the suspension cannot be central. The "handle" is welded on just before the billet enters the furnace. It is removed from the heated billet by means of a pneumatic hammer. The chisel of the hammer goes through the hot handle like a hot knife goes through butter. Fig. 255 shows, although indistinctly, shingles that overlap; they ride on half-rounds which rest on water-cooled beams. The design is identical with that of Fig. 254, except that no water cooling is applied in the latter illustration. The hangers are made of heat-resisting alloy. In Fig. 255 the furnace door has been opened downward. On the discharge

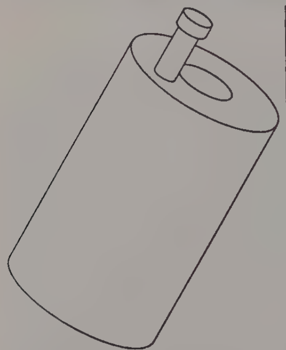

FIG. 256. Eccentric suspension of billet.

side, the door is equipped with a burner that is automatically turned off when the door is opened.

With overhead conveying, the furnace doors should be open just as short a time as possible. This goal is reached by different methods. In one method, the doors are opened, and the whole conveyor is accelerated until one hanger has left the discharge end and another hanger has entered the cold or receiving end. This action is hard on the

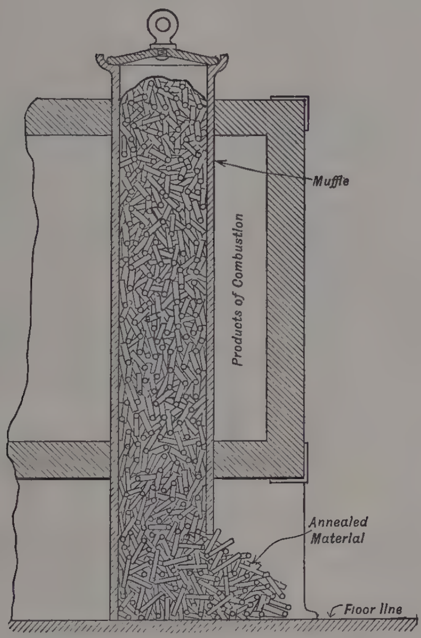

Fig. 257. Vertical conveying through annealing furnace.

conveyor and causes swinging of the suspended objects. In another method, the speed of the main conveyor remains constant, and an auxiliary conveyor is installed at the discharge end. The auxiliary conveyor lifts one hanger off the main conveyor and carries the heated object quickly out of the furnace. As a rule, no auxiliary conveyor is provided for the receiving end, because a longer time of door opening causes hardly any loss of heat or of production at the cold end.

Vertical Conveying. The characteristic feature of the conveying systems described in the preceding sections of this chapter is that the material is conveyed through the furnace in a practically horizontal straight line. In contrast to these arrangements, vertical conveying has been resorted to in several factories, because it saves floorspace. Fig. 257 diagrammatically illustrates a simple method of conveying

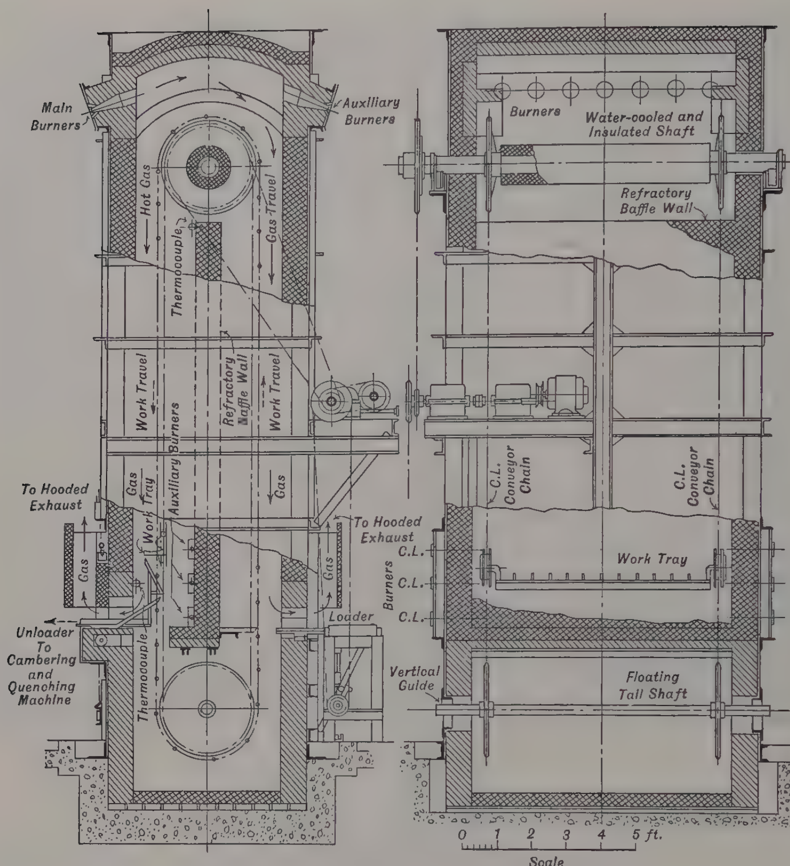

FIG. 258. Vertical conveyor in furnace for heating spring leaves.

which is used for annealing small material. The material is shoveled into the top and moves downward by gravity at the rate at which heated and annealed material is removed from the bottom. The removal at the bottom may be accomplished by shoveling or raking, or else by means of a slowly moving conveyor. It is easily seen that the method illustrated in Fig. 257 has its limitations. It can only be used for heating stock that will move vertically without trouble, and will not be injured by the weight of the overlying charge. The conveying system in question is used particularly for the annealing of small castings, pipe fittings, and the like.

Vertical heating is a boon for crowded factories, the capacity of which is to be increased. An interesting example for this statement is furnished by a vertical furnace for heating automobile springs. It

is illustrated by Fig. 258. Work-holding trays are moved by chains, which are indicated by dot and dash lines. Only one of the many work trays has been shown in both views. The chains are in tension.

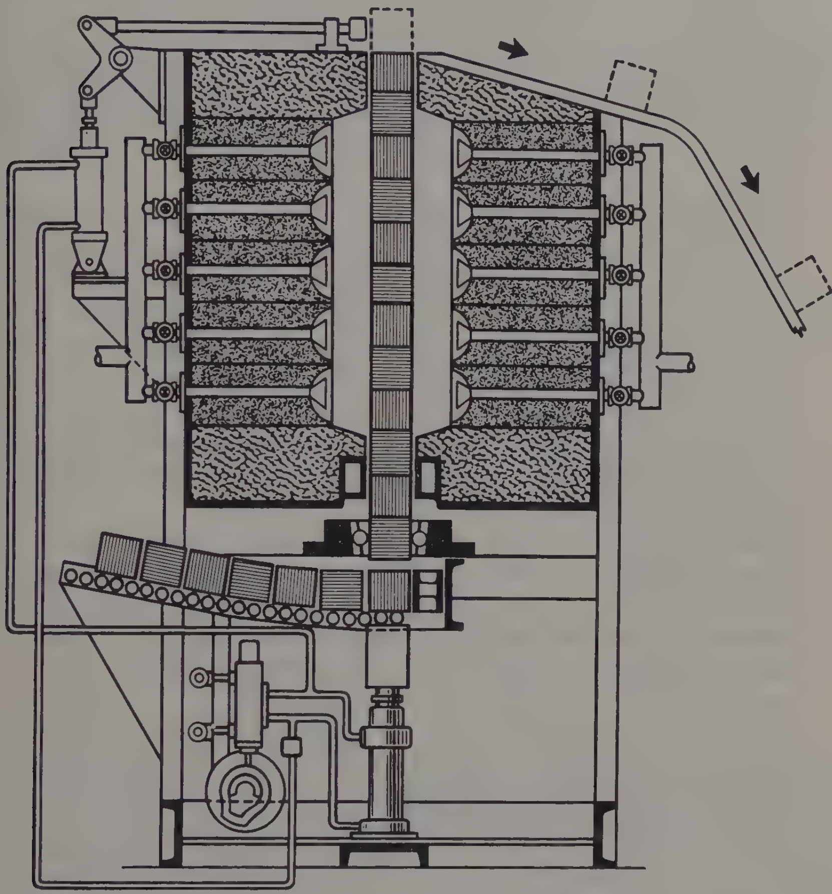

FIG. 259. Furnace with vertically upward feeding of billets. Courtesy of Selas Corp. of America.

Their creep strength limits the weight that can be carried and the temperature in the furnace. The illustration is so well marked that no further comment is needed.

Vertical heating offers certain advantages in the heating of billets and of square blocks to forging temperature. One advantage is that heat can be imparted from two sides or even from four sides. This fact is illustrated by Fig. 259 which shows billets being lifted step by step through a furnace equipped with cup burners. Cam-operated

valves control hydraulic cylinders which lift the billets and send a heated billet on its way. The device for supporting the column of billets is ingenious. Practically the same scheme was used in 1945 for the heating of square blocks by induction. If round billets are to be lifted through a furnace, water-cooled guides are needed for keeping the billets in a vertical line. Vertically downward movement of billets through a furnace has been attempted, but it presents a difficulty with furnace temperatures of 2200 F or greater. The hot sticky billets, held down by the overlying column of billets, present a problem in individual removal.

Transportation by Circular Motion. In many respects circular motion is much more convenient than straight-line motion, a fact which is acknowledged in machining operations and in many other manufacturing processes. A study of the methods of circular conveying to be described in this section will prove that circular transportation indeed deserves extensive use.

The most natural step to take in the application of rotary motion to furnace design is that of providing, within the furnace, a rotating table or hearth. Such an arrangement carries with it certain features which must be discussed.

Since any point on the table describes a purely circular path, its path continually returns within itself; and a piece lying on the hearth is never discharged from the furnace unless it is acted on by some external means, such as removal through a door, or tilting of a section of the hearth or a stationary curved scraper, by both of which actions the charge is made to slide down a chute.

Furnace gases must not escape (at or near hearth level) into the workroom; neither must air be allowed to enter into the furnace, especially if the furnace is filled with a protective atmosphere. In small furnaces this requirement is met by a packing around the driving shaft; in larger furnaces it is taken care of by a sand seal or a water seal.

In a straight production line, the round furnace sticks out to one side like a boil or like a sore finger. This fact is illustrated by Fig. 260. By clever arrangement of the factory this disadvantage can be overcome.

The charge lying or standing on the hearth need not be pushed. In consequence, rotating hearths are adapted to heating shapes that cannot safely be pushed through furnaces. Among such shapes are long rounds lying on the hearth, short rounds with height less than three diameters, standing up, plates, and many special shapes. No trouble doors are needed.

The factors that affect strength and fuel economy of furnaces with rotating hearths are discussed in Volume I. In the present chapter, handling and labor economy are discussed.

Small furnaces with rotating hearths have, as a rule only one door each. The single door must be wide, as shown in Fig. 261, for the purpose of protecting the heated object that is ready to be removed against being chilled by the cold object that has been charged. Handling is practically the same as it is in furnaces of the batch type.

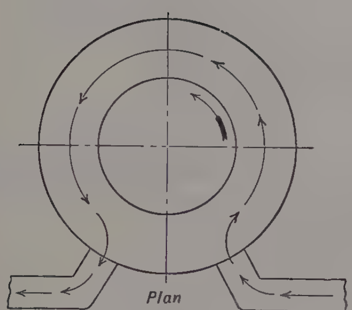

Fig. 260. Diagram of motion of material through furnace with rotating hearth.

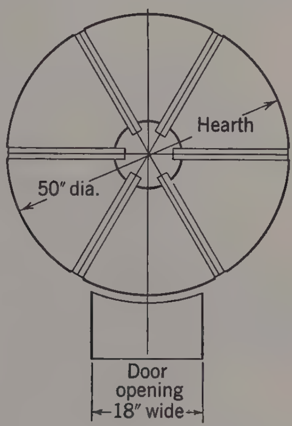

Fig. 261. Small rotating-hearth furnace with wide single door.

Small objects are charged and removed by tongs. Larger objects are moved by equipment that becomes more complicated as the size and weight of the pieces grow. An often-used arrangement consists in a long lever that is supported either from a monorail, as shown (diagrammatically and without clamping devices) in Fig. 262, or rests on a post. The post is part of a rigid carriage the wheels of which travel on rails. This latter arrangement serves for very heavy pieces which must not be allowed to swing. The clamping movement at the furnace end of the lever is usually actuated by compressed air. The air hose is fastened to the lever at its fulcrum. For extra-heavy pieces the in-and-out motion is likewise power-operated. At the operator's end, the lever has two handles (one for each hand). Twisting one handle clamps the tongs, twisting the other handle causes radial (in or out) motion. If heavy pieces have to be lifted, the operator's end of the lever becomes uncomfortably (and sometimes impossibly) long. In such a case the chain of Fig. 262 becomes a hoist which

raises or lowers the fulcrum of the lever. The hoist is operated by a pushbutton switch on one of the handles. Any of the charging machines described earlier in this chapter can, of course, be used and

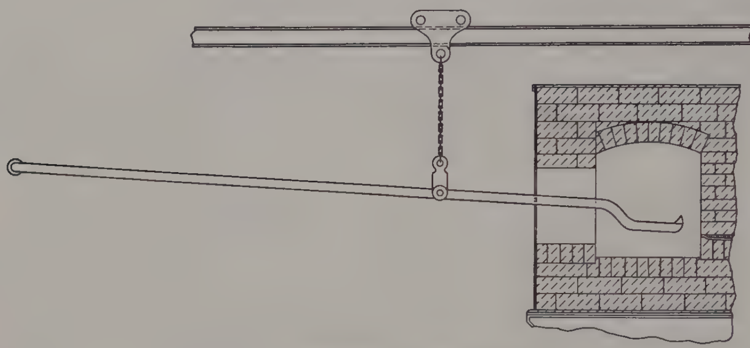

FIG. 262. Long-lever handling device.

have been so used. The suspended lever is pulled out of the furnace far enough to deposit the heated objects on a conveyor which leads to the press, hammer, or rolling mill. The lever of Fig. 262 is often equipped with a pneumatic clamping device.

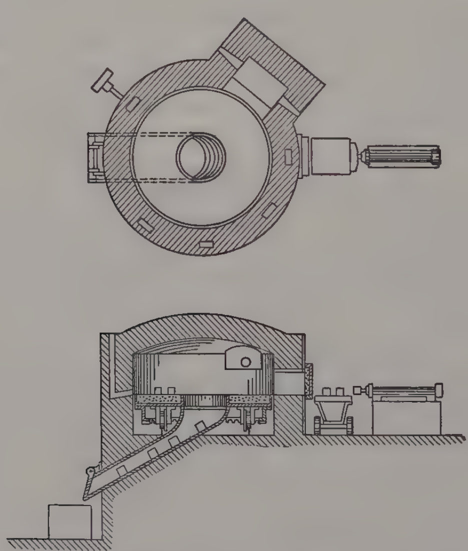

FIG. 263. Small rotating-hearth furnace with central discharge.

A very wide door reduces the heating capacity of the rotating hearth, but it permits handling by one machine and by one man. For

loading and unloading, rotation of the furnace is stopped. The hot piece is removed, the furnace is rotated backwards, the cold piece is charged, and forward rotation for heating is resumed.

If small objects are heated for annealing or for quenching, they can be pushed or raked or dumped into a discharge chute. Figs. 263 and 264 show discharge chutes. In the latter illustration a cam-operated rod tilts a section of the hearth when that section is in line with the chute. Careful loading is necessary to prevent spilling; or else each segment must have high side guards.

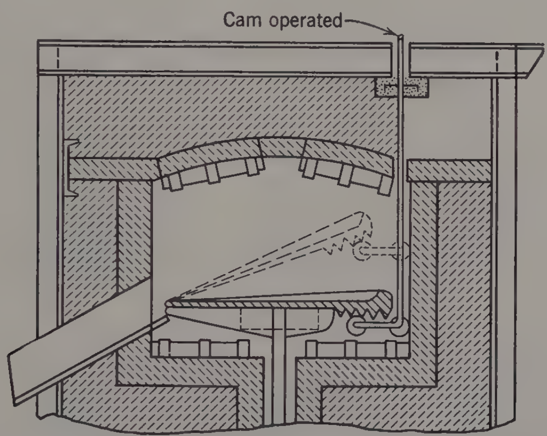

FIG. 264. Automatic dumping device for sectional rotating hearth.

The advantages which the rotating hearth offers with regard to labor saving have in some cases been offset and even nullified by high cost of maintenance. This feature is discussed in Volume I.

Some material that is to be heated on a rotating hearth does not lend itself to being deposited on the hearth and to being removed from it through a door. In such a case the side walls and the roof cover only part of the circumference; an open section serves for handling. A furnace that fits this description is illustrated by Fig. 265. It was built for bright-annealing coils of very thin strip steel. As explained in Volume I, radial heat flow is very slow in coils of thin material on account of the excessive number of air spaces between the layers in the coil. Devices for securing axial rather than radial heat flow are described in Volume I. In the furnace of Fig. 265 this problem is solved by transmitting heat to the two ends (top and bottom) of each coil. A supply of protective gas is picked up below the rotating hearth, passes up through the hearth, and, of course, rotates with it. The

protective gas is turned off manually before the hood over the coil is removed. Each coil has a sand seal, and the hearth has the general sand seal. Fig. 265 needs no further comment except that the furnace is rendering excellent service.

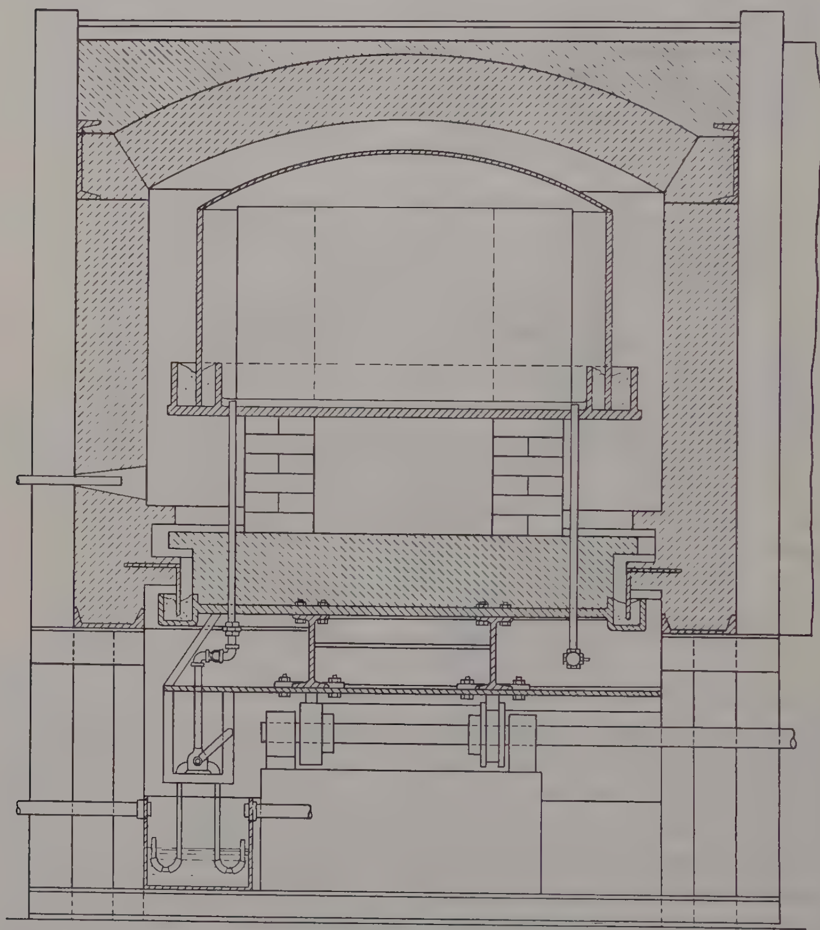

FIG. 265. Section through continuous coil-annealing furnace with rotating hearth. A sector of the hearth is not covered. The open portion serves for final cooling and for changing coils.

Rotating hearths on which scale is formed are cleaned once a week. A sheet is laid on the hearth and through the door. The scale is raked or hoed onto and over the sheet. Care is taken not to drop scale into the sand seal.

Rotating Furnaces. For some forging processes handling is simplified by rotating not only the hearth but the whole furnace. Fig. 266 illustrates the principle. That illustration is a section through a furnace in which the ends of round billets are heated. As soon as a hot billet has been removed from one hole, a cold billet is inserted into the empty hole. At the top of the furnace fuel gas is supplied centrally

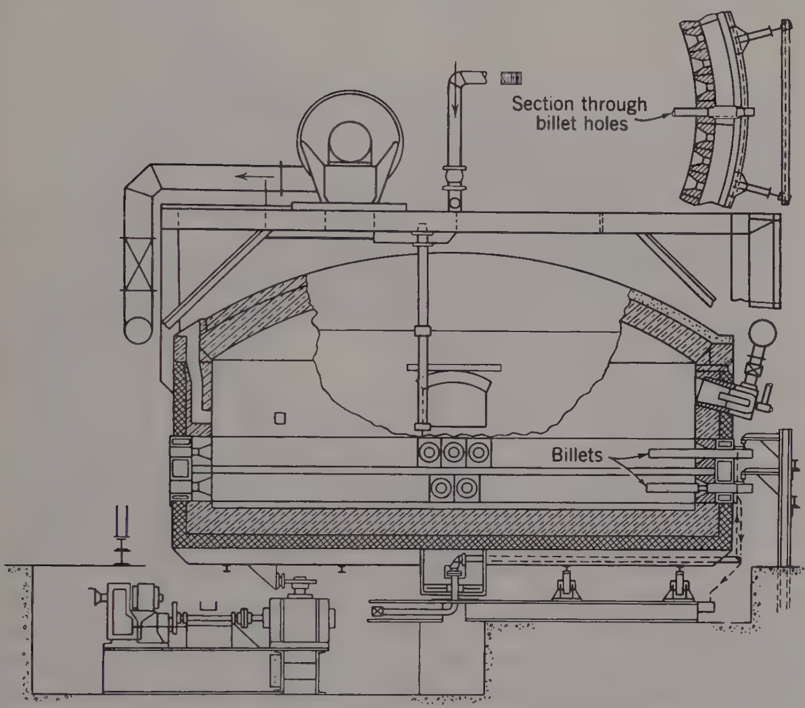

FIG. 266. Rotating furnace for heating the ends of bars.

through a packed rotating joint. Cooling water and electric power are centrally supplied at the bottom. The electric power is used for operating the blower that furnishes air for combustion. The blower is mounted on the furnace and goes around with it.

Helical Conveying. In cement manufacture, lime burning, and metallurgical practice, material is frequently conveyed through furnaces or kilns by means of a motion rather akin to that of the helix. The conveyors are inclined drums into which the material is charged at the top. The rotation of the drum continually tends to carry up the material on one side, in a plane at right angles to the axis of the drum. The material climbs on the side a certain distance or arc only,

the length of which depends upon the coefficient of friction between the material of the tube and the material to be heated. The material then drops back, not in the inclined plane in which it was raised, but in a vertical plane. In consequence, the material passes from the top of the inclined kiln to the bottom with a sort of zigzag motion. The speed with which it traverses the kiln depends upon the inclination of the drum, its speed of rotation, and upon the coefficient of friction between

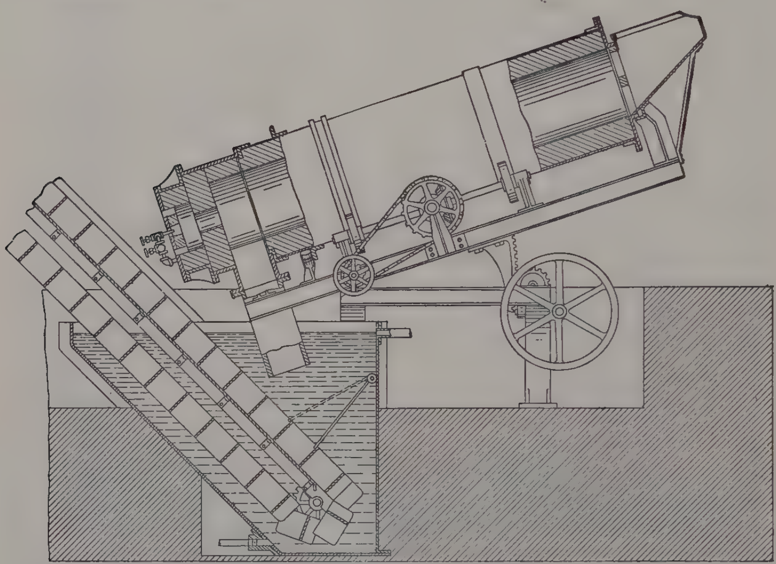

FIG. 267. Rotating-drum furnace. Note adjustment of inclination.

the material of the drum and the charge. The length of a drum cannot be changed easily, and, since we have no control over the coefficient of friction between the charge and the wall material, adjustments are commonly made either by varying the inclination of the drum or else by adjusting its rotative speed. In some cases both adjustments are made.

From the above description of the zigzag motion it is evident that the term "helical motion" is somewhat of a misnomer and yet it probably describes the action of the conveyor better than any other term. It should be noted that in certain other conveyors of the same general type, to be described below, the motion is much more nearly helical. A furnace embodying the motion which was described in the last paragraph is illustrated in Fig. 267. In accordance with the principles stated above, the inclination of the revolving drum can be adjusted by means of the handwheel, working through a worm-wheel set and a

pinion-and-segment set. Incidentally, the illustration shows how the heated material is automatically discharged into a quenching tank and is automatically removed therefrom by means of a chain-and-sprocket conveyor. Some complications are introduced by the necessity of transmitting motion to the revolving drum through the axis of the pivot point, so that motion may be correct at any angle of tilting of the drum. This, obviously, could be avoided by placing the motor directly on the frame of the drum.

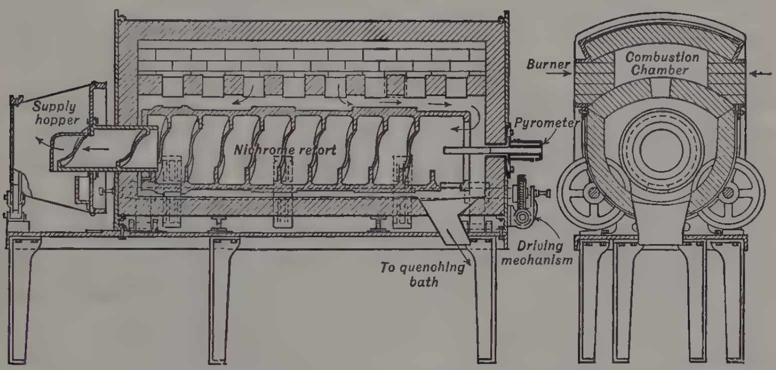

FIG. 268. Automatic furnace of the revolving-drum type. The charge is transported by helical motion.

The smooth drum, as illustrated in Fig. 267, is apparently not suited to conveying round material such as balls or rollers. Material of that description rolls through the inclined furnace along the bottom without being carried up along the sides and without dropping back in zigzag fashion, as explained above. If easily rolling material is to be conveyed, it is preferable to use a horizontal and truly helical conveyor, that is to say, a drum inside of which there is a screw thread. This principle, which is a very old one in the art of metallurgy, is illustrated in Fig. 268. In this type of conveyor the rate of progress of the heating stock through the furnace is definitely given by the pitch of the helix and by the rotative speed of the drum. The quantity of material sent through the furnace depends upon the rate of feeding the material into the drum. The furnace illustrated in Fig. 268 is equipped with a supply hopper (shown at the left-hand side of the illustration) which automatically feeds a certain amount of heating stock into the drum at a predetermined and adjustable rate. It will be seen that the furnace is entirely automatic. For that reason it became very popular for the heat treating of small articles.

The field of the furnace just described is limited. If a piece of material can ride astride one of the ribs, it will be carried around without progressing axially. This statement, in connection with the fact that the material of the retort, no matter whether it be metallic or refractory, loses its strength at high temperatures, assigns a definite field to the furnace. This field is quite large, however, and the furnace is adapted to handle, for annealing, hardening, tempering, or bluing, any pieces of small and uniform dimensions (not too oblong) in brass, copper, steel, or other metals, such as eyelets, ferrules, buttons, caps, cups, coin blanks, steel balls, saw teeth, tacks, screws, rivets, rings, certain types of springs, nuts, punchings, in fact any small pieces which will travel freely and pass through the openings without choking them.

Incidentally, it may be noted that a revolving drum provided with internal helical ribs need not be inclined, whereas a smooth drum must be inclined in order to produce a forward and downward motion of the charge.

The features of automatic loading, transportation, and discharge in drum furnaces interfere with the introduction of a protective atmosphere. For that reason, drum furnaces are not used for metal heating as much as they were used before the introduction of protective atmospheres.

The Charge Is Its Own Conveyor. Wire, chains, and strip can be pulled through furnaces. In the wire industry this method of conveying was in use long before the end of the nineteenth century. Wire is heated while being pulled through a furnace and is processed by passing either through a lead bath or a salt bath or a quenching bath. Several variations of this process are in existence.

If the wires are free from kinks, if they are subjected to sufficient tension, and if they are correctly guided, they can be heated in a large muffle or in an open furnace. Fig. 269 illustrates how 72 strands are introduced into and pulled through a long, oilfired furnace. If the above-stated conditions do not exist, the wires get tangled in the furnace and break. For that reason, some wire makers prefer individual, tubular muffles. A protective atmosphere may be introduced into the muffle or muffles. In many wire factories the wires are heated electrically by serving as resistors, more seldom by induction. Electric resistance heating is illustrated by Fig. 270. It became a success by passing the wires through a contact bath. They are heated by alternating current on the way from the contact bath to the lead pan. The heating time is less than 10 per cent of the time that is required in muffle heating. Scale formation is proportionally reduced. No furnace is required for heating the wires, but they are usually covered

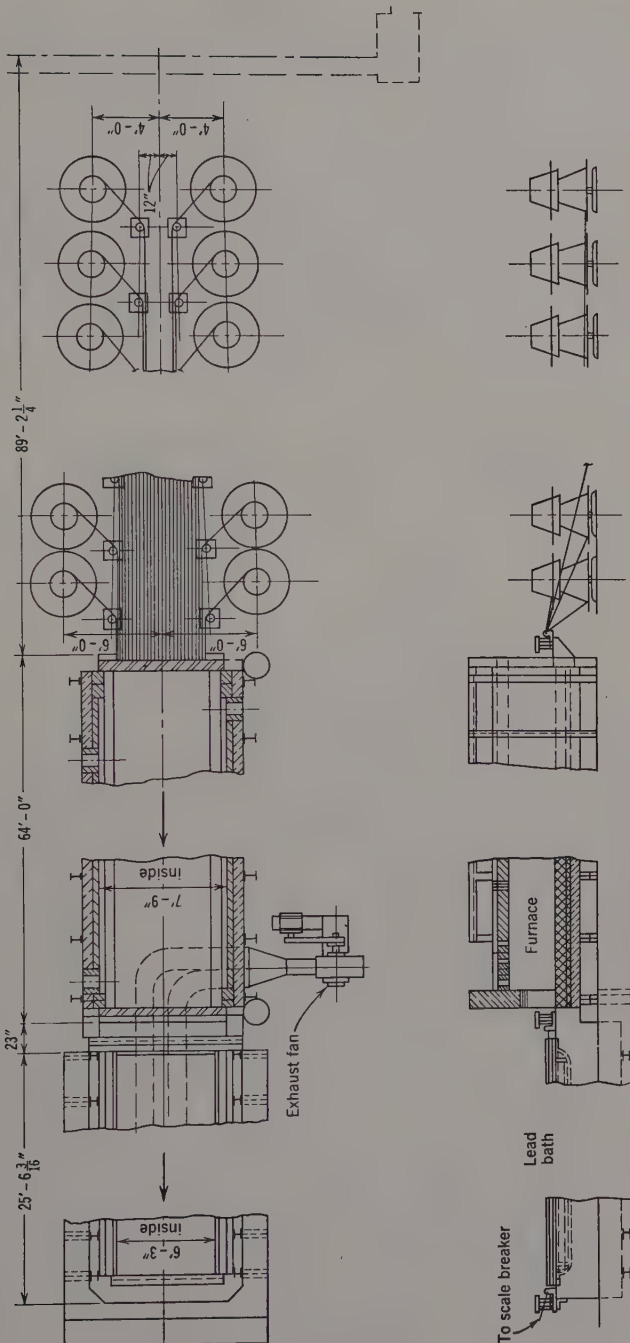

Fig. 269. Furnace through which many wires are pulled side by side.

by a light hood. However, either a furnace or an electric heating device is needed for the contact bath and for the main lead bath. The cold wires entering the contact bath take heat out of it. Both baths freeze up over Sunday.

Continuous pull-through furnaces for heat treating and for hardening of wire are almost identical with the furnace of Fig. 269.

The pull-through furnace for wires is very efficient for quantity production, because many strands travel side by side. As long as everything goes right, the only labor needed consists in welding the front end of a new coil to the tail end of the preceding coil. If a wire breaks, the

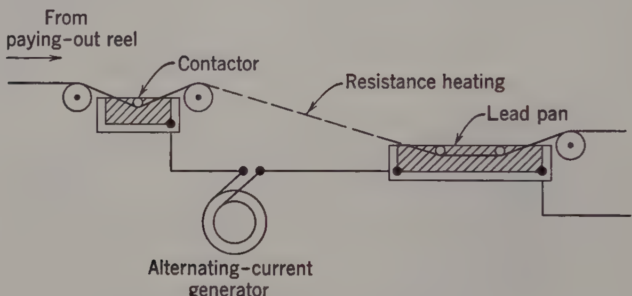

Fig. 270. Resistance heating of wire.

work of mending the break varies with the type of furnace. If the latter be of the individual muffle type, the oncoming wire is fastened to a rod which is pushed through the muffle. In open furnaces or in wide muffles the oncoming wire is "hooked on" (in mill language) to an adjacent wire and is pulled by it through the furnace. By means of tongs or of asbestos gloves the new wire is guided around the pulleys in the lead bath or in the salt bath. This work requires skill, because it has to be done by touch rather than by sight.

Pull-through furnaces for strip were observed by the author as early as 1931. Their development and adoption by the trade have kept pace with the development of the strip mill. Pull-through furnaces for strip heat non-ferrous metals as well as ferrous metals, including plain carbon steel and alloy steel. The metallurgical aspects of continuous strip furnaces are important. Their discussion belongs in books that deal with metallurgy. The furnace engineer must so design the furnace that the specifications of the metallurgist can be met. These specifications concern furnace atmosphere, rate of heating, final temperature, holding time at temperature, and rate of cooling.

Pull-through continuous furnaces for strip have been built for hori-

zontal conveying and for vertical conveying. The horizontal furnace has a limited capacity and serves mainly for heating stainless steel. The strip may hang in the furnace in the shape of a catenary, or else it may be supported on rollers, as illustrated by Fig. 271. Strips are heated by direct firing, if such treatment does not damage the steel. In Fig. 271 the furnace is filled with a protective gas. The idler rollers are made of practically ash-free soft graphite. They are mounted on stainless-steel pins that rest in graphite bearings.

In order to be truly continuous, furnaces for heating strip must be equipped at both ends with loops that contain enough strip for maintaining the flow of strip through the furnace while a new coil is being put into place and while a processed coil is being removed.

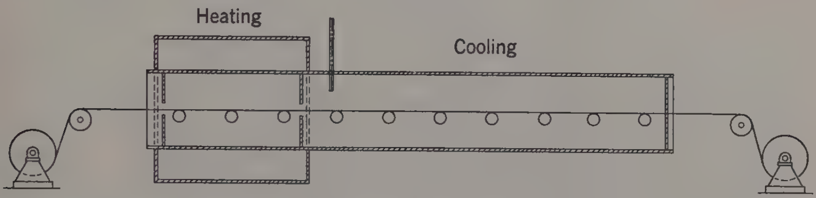

FIG. 271. Continuous furnace for heating strip steel. The strip is pulled through the heating and cooling sections.

In high-tonnage works the horizontal continuous furnace occupies too much floorspace in one direction. In such works vertical furnaces, also called tower furnaces, are installed. Fig. 272 diagrammatically illustrates this type of furnace. In practice the number of up-and-down travels is greater than shown in the illustration, there being as many as five heating units and nine cooling units. The heating sections and the first cooling section are filled with a non-explosive protective gas. Either electric resistors or radiant tubes serve as heating elements. Heating and cooling are adjustable within wide limits. Experiments are under way for heating strip in a liquid atmosphere, but the difficulties are so great that the method has not yet been reduced to practice.

In order to be really continuous and labor saving, the tower furnace needs much auxiliary equipment. This equipment is neither described nor illustrated here, because it is extraneous to the furnace; however, a mere enumeration of the auxiliary equipment is of interest. On the entry side the following is needed: Pneumatically operated entry ramp, uncoiler, shear, seam welder, cleaner, scrubber, rinse tank, dryer, first bridle unit, entry looper, and second bridle unit. On the delivery or exit side are installed: sample punch, third bridle unit (tension bridle),

shear, recoiler, pneumatically operated exit ramp. The auxiliary equipment takes up more floorspace than the heating and cooling unit. The tower furnace is not strictly a pull-through furnace; the direction-changing graphite rollers at the top are motor driven.

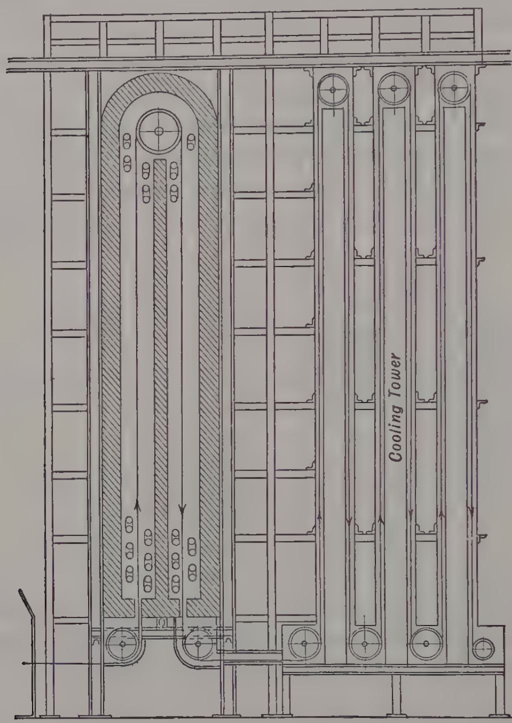

FIG. 272. Tower-type furnace for annealing strip steel. In the heating tower (left) radiant tubes are provided all the way up.

The continuous strip furnace resembles the continuous wire furnace inasmuch as very little labor is required when things go right. Unfortunately, there are times when things go wrong, for instance, when the strip breaks in the furnace. These breaks are caused by a poor weld or by tears that originated in the rolling mill. Breaks in the furnace are becoming smaller in number, because the high cost of breaks (in the strip mill and in the furnace) has forced attention on the causes. If a break occurs, the furnace is purged and openings are made at the top and at the bottom for the purpose of locating and mending the break. The strip is made to drop through an access door at the bottom; it is then fastened to a strip or wire that was dropped through an opening at the top. The broken strip is hoisted to the top,

laid over the roller, and is weighted. Rotation of the top roller moves the strip far enough to have it connected to the other end of the break by means of a filler piece, which is removed before it reaches the coiler.

The minimum production for which tower furnaces can be recommended lies between 10 and 15 tons per hour of light-gage strip; for strip of heavier gage the corresponding range lies between 15 and 20 tons per hour.

Automatic Conveyors for Salt Bath Furnaces. Mechanized conveying through molten salts must be performed by overhead (i.e. above the bath) conveying. It requires one means for bringing the charge

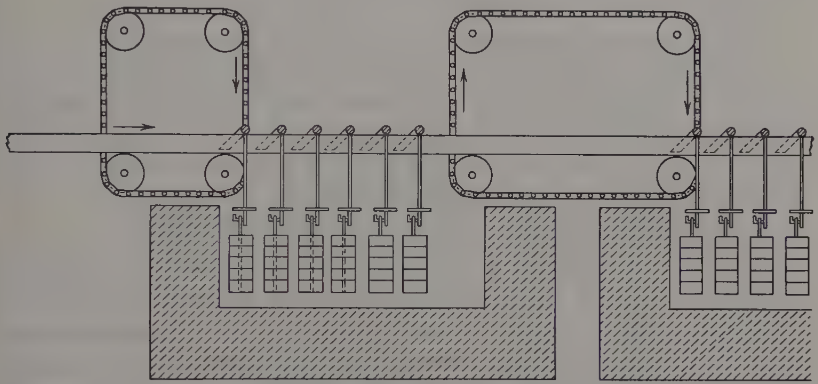

FIG. 273. Continuous salt-bath furnace.

to the bath, a second means for lowering the charge into the bath, a third means for moving the charge horizontally through the bath, a fourth means for lifting the charge out of the bath, and a fifth means for transporting the charge away from the bath. Some of the processes may be carried out by one apparatus. Practically the same equipment is needed for a quenching bath and also for a draw bath.

The apparatus is schematically illustrated by Fig. 273. One conveyor lifts the charge up and over, and lowers it into the bath, where horizontal transportation is taken over by another conveyor. Having traveled through the bath, the charge is automatically picked up, lifted, carried horizontally, and lowered for the next process, which is shown in the illustration to be a quench tank.

Vertical movement into and out of the tank may be quick, but horizontal movement (which in the illustration has the same speed as the vertical movement has) must be slow. If it were rapid, the charge would be swinging at the end of the horizontal travel. The period

of oscillation depends on the length of the pendulum, and the charge is very apt to land on the rim of the container instead of dropping into the bath. The slow, roundabout travel causes the temperature of the charge to drop between heating bath and quenching bath.

The conveyor reaches into the salt bath through a narrow slot, for the purpose of saving heat and also for preventing discomfort to attendants. Evidently, the chain loop and the horizontal conveyor cannot lie in the same plane. Two horizontal conveyors are provided outside the bath. They are, in the illustration, driven by a ratchet motion. The hangers that carry the charge must be so designed that they can automatically be transferred from one conveyor to the next one.

This concludes the description of the principal types of conveyor mechanisms used for furnaces. It is needless to say that conveyors are also used for bringing the material to the furnace and for removing it from the furnace. However, the present volume is not a treatise on automatic conveying machinery in factories. For that reason the conveyors outside the furnace, no matter how interesting they may be, cannot be discussed or described here in detail.

Devices for Comfort and Convenience. There exists, however, another phase of furnace construction which, although not directly labor saving, must be discussed here because it saves labor indirectly, by increasing the convenience and comfort of the various workmen around the furnace. It is a well-known fact that men who are not exposed to excessive heat or to obnoxious fumes can and will do more work in a given time than those who are exposed.

The equipment in question is used more particularly in connection with fuelfired furnaces than with electrically heated furnaces. Electric heating produces no fumes; electric furnaces are always well insulated, because of the high cost of electric heat. It should be understood that good insulation is of equal benefit to the attendants with fuelfired furnaces, and that it should be applied wherever feasible.

It is quite customary to discharge the products of combustion of clean gases and of oil directly into the workshop. Though this procedure is permissible for a small furnace in a large, well-ventilated shop, it is not advisable in other places. Hoods or canopies which collect the fumes and discharge them through the roof (or, at least, carry them to a higher level) are much to be preferred. These hoods assume various shapes, depending upon the type of furnace which they serve and upon the shape of the building in which they are located.

A diagrammatic sketch of a furnace with hoods at both ends is shown in Fig. 274. The furnace in question is intended to discharge all the products of combustion through the door openings, so that the room in

which the furnace is located is filled with the fumes unless they are taken away, as indicated. Hoods for carrying away the products of combustion should be considered at the time when the furnace installation is planned, because their consideration may influence the location of the furnace in the factory. It is quite evident that hoods carried through the roof will frequently interfere with crane operation unless the furnace has been properly located with a view to avoiding such interference. There is no doubt that interference with crane operation is the principal reason for the limited application of furnace hoods. Underground flues and stacks should take the place of hoods if the

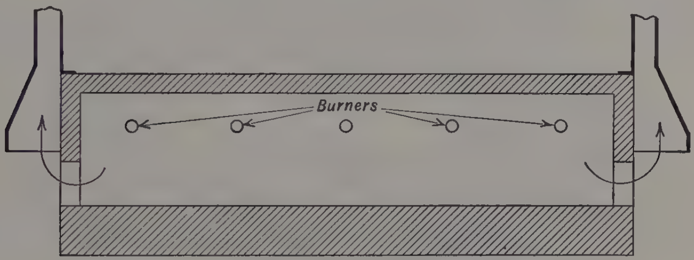

FIG. 274. Arrangement of fume-collecting hoods.

hoods interfere with crane operation. Crane operators deserve consideration. The cab of a traveling crane can be cooled (air conditioned) without any difficulty, but is almost impossible to supply fresh air from the outside to the crane cab. Even if stacks are provided for carrying away products of combustion, a hood will often be found convenient because industrial furnaces work with a slight pressure in the heating chamber. If the door must be opened frequently or kept open all the time, the gases which are constantly being discharged will fill the working room unless they are carried off by a hood which leads up to vents in the roof.

Bolt-heading furnaces and other furnaces for drop-forge work are particularly trying on the operators because all the products of combustion are discharged through the constantly open doorway directly into the face of the attendant. Water-cooled shields, hung in front of the doors, are a good addition to these furnaces. The water-cooled shields are hung sufficiently far away to allow most of the products of combustion to rise between the shield and the furnace proper. Water is discharged from a spray against the top of the shield and is collected by a trough at the bottom. The space between the shield and the furnace can also be connected to a hood for carrying the products of combustion away. The shield, which is sometimes called a false front, is not

always water-cooled. A heavy asbestos board riveted to the furnace side of the shield is very effective.

Pipes for preheating combustion air are often placed in the space between the shield and the furnace, as shown in Fig. 275. On account of the great velocity with which the products of combustion issue from the door opening, they tend to rush under the shield into the workroom, instead of going up into the space between the shield and the furnace.

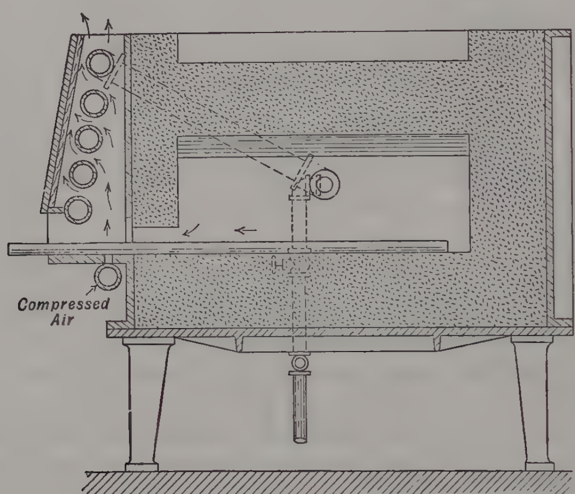

FIG. 275. Drop-forge furnace with protecting shield and air blast.

An air pipe, laid underneath the projecting bars in front of the door and provided with upwardly directed openings, helps to blow the products of combustion in the proper direction. This air pipe is likewise indicated in Fig. 275.

A similar purpose is served by chain doors, which are described in Volume I. In several factories chain doors were tried and were discarded because the heating stock caught on the chains and caused trouble. The regular makers of chain doors have had experience with such conditions and, wherever the material might catch in the chains, equip the bottom of the chains with pipes instead of links. It is scarcely possible that anything will catch on the round pipes which form the bottom of the chain doors.

In Volume I the statement is made that, as far as strength and durability are concerned, water-cooled doors are not necessary on heating or annealing furnaces. They are, however, occasionally applied for the sake of the convenience and comfort of the attendants, although their

use may result in somewhat increased fuel consumption. A homemade and very effective water-cooled door is shown in Fig. 276. It will be seen that this door consists of a steel casting to which a steel plate is welded. The only difficulty in this construction consists in getting a casting which is sufficiently free from porous places to hold water. For that reason, doors built from welded-steel plates are preferred. Water-cooled doors are heavy.

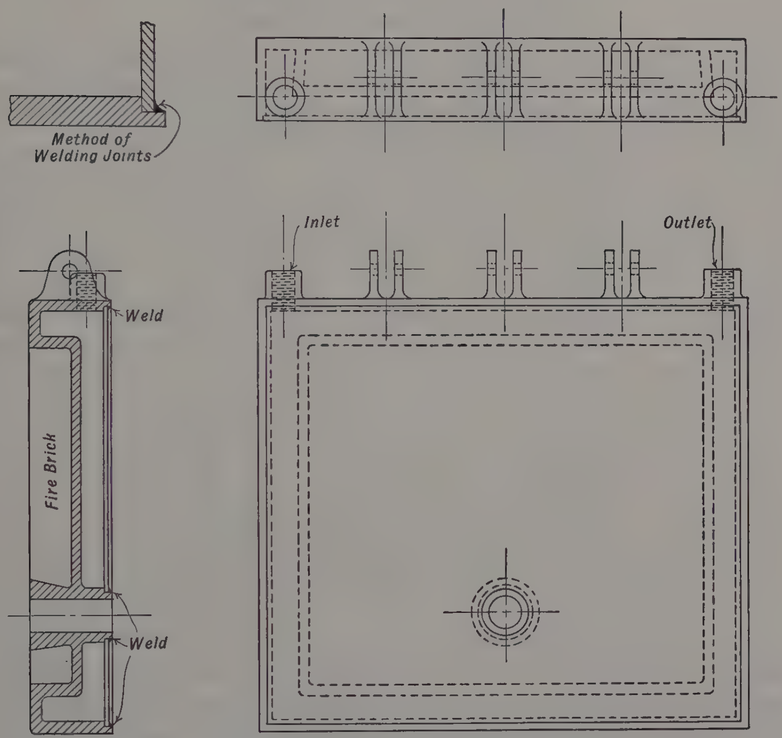

FIG. 276. Water-cooled furnace door.

A sufficiently effective protection against heat from thin doors is obtained by the design in Fig. 277, which has the advantage that it can be applied to existing doors. By means of a few stud bolts, a thin plate is fastened in front of the door. The plate acts as an air-cooled radiation screen. It is made even more effective by being built of two still lighter plates with an asbestos sheet in between. In this construction, buckling may occur.

In industrial work there are several types of furnaces in use in which the nature of the operations is such that men must work in front of a

constantly open doorway. In pipe welding, for instance, men continually must observe the condition of the pipe blank (skelp) and must push it out into the welding die or rolls at the very instant the skelp has been heated through to a white heat. In that case neither a chain door

Fig. 277. Furnace door with radiation screen.

nor any similar device can be employed. For protection, the men wear masks in front of their faces and are cooled by fans. There are large fans on the market for this purpose, under the name of Man Coolers. In some furnace work conditions arise in which an attendant must stand at a hot and uncomfortable spot for a long time; air is then blown through conveniently located ducts and is directed to give the greatest possible comfort to the furnace attendant.

CHAPTER VI

CRITICAL COMPARISON OF FUELS AND OF FURNACE TYPES

Basis of Comparison. Whenever a new furnace or a group of new furnaces is to be installed it becomes necessary to select the best type of furnace and the most suitable source of heat energy, the object being, of course, to obtain the lowest cost per unit of finished saleable product. Comparisons are odious, but they must be made in order to secure the survival of the fittest (the *better* is the enemy of the *good*), with a minimum of expense and trouble to users and sellers of fuels and furnaces. The whole subject is a very delicate one because those who make their living by building and selling furnace equipment may resent unfavorable comparisons. For that reason, facts only are cited and personal opinions have been omitted. In contrast to other chapters, the present one will appear rather unscientific and filled with generalities; but it is true that in all walks of life we can be truly scientific in a moderate degree only, and that we must make important decisions on the strength of judgment derived from a mass of more or less incoherent information. The old saying still holds true that an engineer is a man who can draw sufficient conclusions from insufficient premises.

The comparison of different fuels and of different furnace types involves a few duplications of statements that are found in preceding chapters.

The following tabulation (Table XVII) gives an approximate idea of the number of combinations which are possible in furnace work. It will be noted that six subheadings have been selected, namely, Source of Heat Energy, Utilization of Waste Heat, Method of Heat Transfer, Method of Handling Materials, Method of Heat Application, and Nature of Furnace Atmosphere. It is proposed to compare critically the elements under each of these six subheadings. The question of automatic or manual control of furnace temperature might also be discussed in this chapter; however, Chapter III is so explicit that no further discussion is needed here.

Since any element in any one of the subdivisions may be combined with any other element in the other subdivisions, the number of pos-

TABLE XVII

Classification of Elements for Critical Comparison of Fuels and Furnaces

Source of Heat Energy	Utilization of Waste Heat	Method of Heat Transfer	Method of Handling Materials	Method of Heat Application	Furnace Atmosphere
Electricity	In preheating stock	Open chamber	Fixed hearth	Partial heating	Products of combustion
			Pit furnace	Heating stock is electrical resistor	
Gaseous fuels		Charge in muffle	Car-bottom type		
	In waste-heat boilers			Induction heating	Air
Liquid fuels		Flame in muffle	Continuous furnaces		
			Pusher type	Underfired type	Protective atmosphere
Solid fuels	By preheating fuel or air in regenerators and in recuperators	Salt bath and lead bath	Conveyor type	Sidefired type	
			Drum type	Overfired type	
			Rotating hearth		
		Radiation		All-around heating	
		Convection			
				Recirculating type	

sible combinations and of furnace types runs into the thousands, as a comparatively brief mathematical calculation shows. The large number of possible combinations has led to the decision to compare critically only the elements or possibilities contained within each of the subheadings.

Sources of Heat Energy: Their Influence upon Furnace Design and upon Cost of Industrial Heating. The sources of heat energy fall into two broad subdivisions, namely, (1) heat energy derived from the combustion of fuel in the furnace (or in an adjacent combustion chamber) and (2) heat energy derived from conversion of electrical energy. The general properties of fuels are discussed in detail in Chapter I. In the present chapter a comparative summary is given of the sources of heat energy with a view to determining their effect upon the production of perfectly heated material and upon the cost of such heating.

The cost of fuel or other heat energy is, in many instances, an exceedingly small fraction of the total cost of the manufactured product (fuel cost accounts for part only of heating cost). When this condition holds true, the effect of the form of energy upon the quality of the finished product is important, and the unit cost of energy per Btu is not a matter of consideration. But there are other situations in which the fuel cost is a large item in the total cost of the finished product and in which the effect of the type of fuel upon the final product is almost negligible. In such cases cheapness of fuel per unit of heat is the deciding factor.

The cost of fuel or electricity for a given heating process depends principally on two factors: (1) the cost of a million Btu generated by complete combustion and (2) the fraction of the combustion heat that remains in the furnace. A third factor might be added, namely, the fraction of the charge that is improperly heated because of the nature of the fuel. Similar considerations apply to electrical energy.

With regard to item 1, Chapter I furnishes information on fuel costs that prevailed a short time before this book went to press. Very detailed information on the cost of coal, oil, and natural gas may be found in "Comparative Economics of Open-Hearth and Electric Furnaces" published in 1953 by Bituminous Coal Research, First National Bank Building, Pittsburgh 22, Pennsylvania. In this book costs are given up to the years 1950 and 1951 for the various states. On page 62 of the same book a forecast is given of the cost of fuels up to the year 1975. The forecast assumes that, although the cost of coal has risen steadily in the past, its cost will remain constant from now on because of greater mechanization of the mines. This forecast disregards the fact that the number of mines which can be mechanized

to advantage is steadily becoming smaller. If the degree of mechanization remains constant, the cost of coal must rise more quickly than the cost of oil and natural gas because every pound of coal has to be brought up from the ground by men, whereas oil and gas come up voluntarily after wells have been drilled.

The rising cost of coal is reflected in the cost of fuels that are derived from coal. Such fuels are coke, producer gas, retort gas, water gas, coke-oven gas, blast-furnace gas, and tar.

Item 2, the heat that is available at furnace temperature, is bound up with the adiabatic flame temperature of the fuel. Adiabatic flame temperatures are given in the first chapter. The heat that is carried out of the furnace by the products of combustion is given in Volume I.

The cost of fuel also depends on the location where it is to be burned. Coal is at present transported by water or by rail or by both. It is also transported by truck on public highways. Natural gas and oil are transported long distances through pipe lines. Electrical energy is very cheaply transmitted by wires.

It might be mentioned that, in spite of growing costs of coal and of labor, the price of the kilowatt-hour has increased very little, if any. Higher pressures and temperatures of steam have reduced the amount of fuel needed for generating a kilowatt-hour; and larger units of boilers and turbines have reduced the cost of labor per kilowatt-hour. It must, however, be realized that both lines of progress have just about reached the limits that are physically possible and economically sound. It may, therefore, be expected that the cost of electrical energy will, from now on, rise with the cost of coal and with wages. Another fact worth mentioning is this: The utilization of electrical energy varies but little with temperature. With rising furnace temperatures, more heat flows outward through the terminals, but the amount of lost heat is comparatively small.

For general, all-around use the favored sources of heat energy in the United States are natural gas, electrical energy, and fuel oil. Combination burners that are suited for burning gas, or oil, or both are being installed in increasing numbers. Many furnaces for heat treating are heated either by electricity or by natural gas that is burned in radiant tubes. The choice is made almost entirely on the basis of local rates for gas and electricity. Electrical trade papers record every case in which a fuelfired furnace has been replaced by an electrically heated furnace; and gas-minded papers record every case in which an electrically heated furnace has been replaced by a gasfired furnace. With correct design both sources of heat energy produce equally good results.

In steel works, home-made by-product gas, blast-furnace gas, and tar are "must" fuels. Other fuels are not bought except that coal is burned in boiler furnaces. In case of a strike or during a severe business depression, natural gas is burned under the coke ovens, if the gas companies have it to spare.

In countries without abundant supplies of oil and natural gas, other fuels must of course be burned. City gas (a mixture of retort gas and water gas) is an excellent fuel for furnaces. Clean producer gas is another good fuel. Its use is uneconomical for high furnace temperatures, unless either the fuel or the air or both are preheated. Electrical energy is available in all countries that have coal deposits or water power. It should be mentioned that the iron and steel industry is more than 1000 years old in several European countries and that in those countries excellent heating and heat treating was done with charcoal and is even now being done with coke. Very few industrial countries are blessed with (or spoiled by) the abundance of fuel that exists in the United States.

Butane and propane are stand-by fuels. They serve as principal furnace fuels in small furnaces. They are burned in large furnaces during war periods, if the government bears the cost.

In the United States, powdered coal, which is a standard fuel in boiler furnaces, is, with few exceptions, an emergency fuel for wartime use. A few forge shops furnish the exception.

Most fuels are suited to temperature control and to combustion control. Control is sluggish with coal and coke. Perfect combustion control with raw producer gas requires thoughtful design and careful operation.

In several places in this volume powdered coal is called an emergency fuel. In corroboration of this statement, the following paragraph is quoted from a letter by the Babcock and Wilcox Co., who have long and varied experience in the burning of powdered coal: "The only thing that has prevented its extensive use in the steel industry is the problem of ash deposits not only on the product, but in the furnace and flues. Since, in many cases, the gas outlet temperature runs close to the deformation temperature of the ash, the ash fuses on the walls to such an extent that frequent shutdowns are necessary for cleaning the flues. This is particularly serious in connection with modern furnaces where recuperators or heat exchangers are being used. Very little or no effort has been made in the past to cope with this problem, and as long as fuel oil and gas are plentiful, even at premium prices, the industry will favor these fuels."

Utilization of Waste Heat. When speaking of waste heat, most

furnace men have in mind the sensible heat in the products of combustion, although there are other items of waste heat, namely, unburned combustible in the outgoing products of combustion, heat lost through the walls, and heat traveling out through the terminals of electric-heating elements. In practice, the opinion of the furnace men is correct, because in more than 95 per cent of cases the sensible heat in the products of combustion is the only waste heat that is salvaged.

In the selection of furnaces it is almost invariably necessary to decide whether a furnace shall be of the simplest possible type, without any utilization of waste heat, or whether it shall be of a more complicated type, in which waste heat is utilized. To a large extent this question is discussed in Volume I. It remains to review the statements made there and to supplement them by a summary of the advantages and disadvantages of the different methods of heat utilization.

Since all commercial fuels produce flame temperatures which are sufficiently high for any industrial heating (up to 2300 F), the advisability of spending money for heat salvage depends entirely upon the possibility of getting back the investment by savings in operation. In connection with furnaces which are used very intermittently, heat salvage does not pay because the saving effected by reduced fuel consumption is very small in comparison with the investment which must be made in order to effect that saving, even if the continued rise in the cost of fuel is taken into consideration.

If, contrariwise, a furnace is operated rather continuously, without long intermissions, and particularly if temperatures in excess of 1600 F are carried in it, the cost of equipment for heat salvage pays dividends. A moderate amount of preheating of the stock pays for itself in almost all furnaces, even in intermittently used furnaces, such as those for hardening high-speed steel, in which a preheating chamber is arranged above the regular heating chamber at very little additional cost. It pays in many frontfired continuous furnaces, as is evident by a study of the curves in the chapter on continuous furnaces in Volume I. From these curves it is clear that the utilization of fuel in frontfired continuous furnaces is quite good if the rate of heating is so low that the products of combustion leave at a temperature below 1300 F. In the heating of steel this corresponds to a rate of 45 to 60 lb of steel per (sq ft of hearth, hour); the fuel consumption rises as the rate of driving the furnace is increased. If frontfired continuous furnaces are driven at the above rate of heating, that is, between 45 and 60 lb of steel per (sq ft of hearth, hour), additional heat-saving devices, such

as regenerators or recuperators or even waste-heat boilers, pay only a small interest on the investment because the heat in the products of combustion is very well utilized by the preheating of the heating stock.

Although theoretically the salvage of heat in pusher-type furnaces can be carried very far, practice imposes a limit on heat salvage by preheating the stock. The furnace becomes very long, the pusher force is increased, the danger of buckling and climbing of the stock becomes

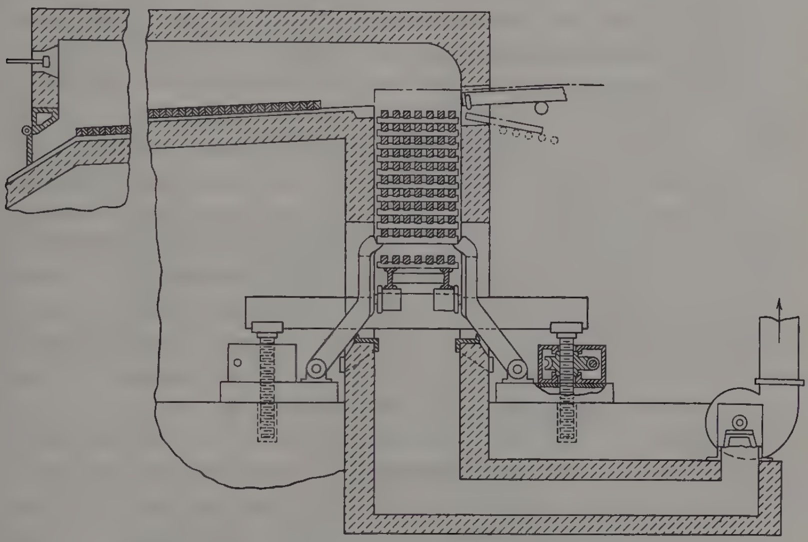

Fig. 278. Vertical preheating of billets.

uncomfortably great, and the wall loss grows. Two means exist to combine heat salvage with a short furnace. One method consists in lengthening the travel of the stock in the furnace by moving the stock first vertically and then (almost) horizontally. The second method consists in passing the hot products of combustion through a recuperator.

Fig. 278 illustrates the first method. The bars that are to be heated are laid on cross bars (they are palletized) and are lifted until lateral supports, called "dogs," drop into place and hold up the stack of bars. The arrangement is similar to the one shown in Fig. 259, but is more complicated. It is doubtful whether this method of combining a short furnace with thermal efficiency will be adopted by furnace builders. Again referring to Fig. 278, it can be seen that laying the bars in spaced relation on the cross bars and, later on, removing the cross bars, which have become hot, are not labor-saving features. The

heat-absorbing stack of billets was introduced at a time when recuperators had not yet reached their present state of perfection.

Practice has adopted the second (above-mentioned) method of building a short and yet efficient furnace. In the United States, early metal recuperators failed sadly, and furnaces were equipped with tile recuperators. Then came combination recuperators, refractory at the hot end and metallic at the cooler end. At the time of this writing, all-metallic recuperators of correct design and material are taking over. Furnaces have been shortened even more by adding side burners to the usual front burners. In that case the products of combustion leave with a high temperature, which is hard on recuperators of incorrect design.

If the charge can be heated and cooled in the same continuous furnace, little heat is wasted. Such processes are the burning of ceramic ware and annealing. In the tunnel kiln, the outgoing products of combustion preheat the incoming ware, while the outgoing ware preheats the incoming combustion air. In a heat-tight furnace of infinite length hardly any fuel would be needed. The first cost of the furnace grows with the length and with the amount of insulation. The most economical length of furnace and thickness of insulation are a compromise between first cost and continued cost of fuel.

In electrically heated annealing furnaces, there are no products of combustion that could preheat the incoming ware, and no combustion air need be preheated. Such furnaces have been built with two lines of ware moving in opposite directions. They preheat and cool each other. In the center of the length of the furnace electric resistors are mounted.

Tunnel kilns and similar furnaces utilize waste heat very effectively. However, they have metallurgical limitations with regard to rate of heating, holding time at temperature, and rate of cooling.

The amount of heat that can be salvaged by recuperators and by regenerators is given in Volume I, and so is the required heat-transmitting surface given. It remains to discuss the economics of heat salvage. The ratio of recoverable heat to heat left in the furnace is given by the expression:

$$\frac{\text{Temperature of gases leaving furnace} - \text{Room temperature}}{\text{Adiabatic flame temperature} - \text{Temperature of gases leaving furnace}}$$

This equation is an approximation, because the specific heat of the products of combustion varies with the temperature. Evidently, more heat can be recovered from fuels that have a low flame temperature than can be recovered in the combustion of fuels that burn with a high

flame temperature. The higher the furnace temperature, the greater is the recoverable heat. It is, of course, impossible to cool the gases to room temperature unless an infinitely large, heat-tight recuperator is installed. It is also impossible to have the temperature of the gases that enter the recuperator equal the temperature of the gases that leave the furnace. The result of both facts is that it seldom pays to recover more than 60 per cent of the ideally recoverable heat.

If, for example, a slab-heating furnace is fired with a rich fuel that has an adiabatic flame temperature of 3800 F, and if the products of combustion leave the furnace with a temperature of 2400 F, then 1400 F have been utilized in the furnace. The recuperator can utilize 60 per cent of 2400 — 100 or 1380 F. It practically cuts the fuel consumption to one half. If a furnace of this type costs 100 units, then the recuperator, installed, costs 35 units. This means that, by spending 35 per cent more, almost one half of the fuel is saved.

The cost of a recuperator depends upon the size of the heating surface, on the material of the heat-transmitting surface, and on the amount of fabrication that is required. The square feet of heat-exchanging surface can be computed from Volume I; the material depends upon the temperature of the heat-exchanging wall; the extent of fabrication depends upon the design of the recuperator. The product "heat-exchanging surface × wall thickness" furnishes the volume and the weight of the alloy in the heat-exchanging wall. The cost of unit weight of alloy depends upon the composition of the metal and upon its form (such as castings, plates or tubes). Roughly, the cost of the recuperator lies between the limits of 2½ and 3½ times the cost of the alloy. The lower factor applies to high alloys, and the higher factor applies to low alloys. The excess of the factor above *one* allows for casing, fabrication, and installation.

Well-planned and well-built recuperators fail to give the expected results, if furnace operation is faulty. The charging door of a continuous furnace may be open too wide. If furnace pressure is high and if the stack damper is down too far, most of the products of combustion escape into the open without reaching the recuperator. Contrariwise, if the furnace pressure is low and the stack draft is great, cold air is sucked into the recuperator. And, if much unconsumed combustible matter is in the products of combustion, secondary combustion in the recuperator results in temperatures that are higher than those for which the recuperator was designed. Such temperatures shorten the life of certain parts of the recuperator, and the damaged parts must be replaced at frequent intervals. Therefore, the recuperator must be easily accessible. The statement that it is wrong to place a recuperator

under the furnace must be repeated. In western Europe, recuperators are located in convenient places near furnaces. Fig. 279 is a vertical recuperator, although the fuel consumption per unit weight of heated for a large furnace. These recuperators (of German design) are not clogged by dust in the products of combustion.

Some furnaces do not lend themselves to being equipped with recuperators. An example of this type is a furnace with many vents that

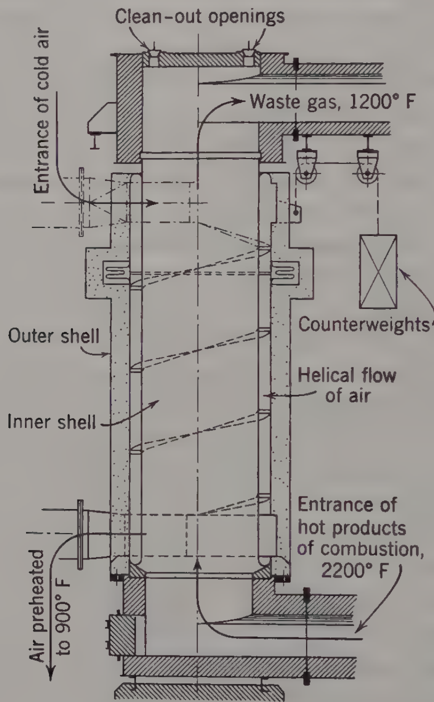

Fig. 279. Detached recuperator for small or medium-sized furnaces. Suitable for dust-laden products of combustion.

are spaced some distance apart. In such a furnace, the installation of a recuperator requires the collecting of the several streams of products of combustion through well-insulated ducts into a common, likewise well-insulated duct that leads to the recuperator. It is, of course, possible to install an individual recuperator at each vent and to lead the preheated air to the nearest burner; the cost of this arrangement is great. For the same reason, recuperators are not installed on hairpin radiant tubes that heat hardening furnaces and draw furnaces.

The "in-line" aggregation of barrel furnaces, which is schematically illustrated in Fig. 146, is likewise not suited to being equipped with a recuperator, although the fuel consumption per unit weight of heated material is greater in furnaces of this type than in furnaces of other types. The owners of such furnaces have spent considerable thought on applying recuperators, but no practical solution of the problem has been found.

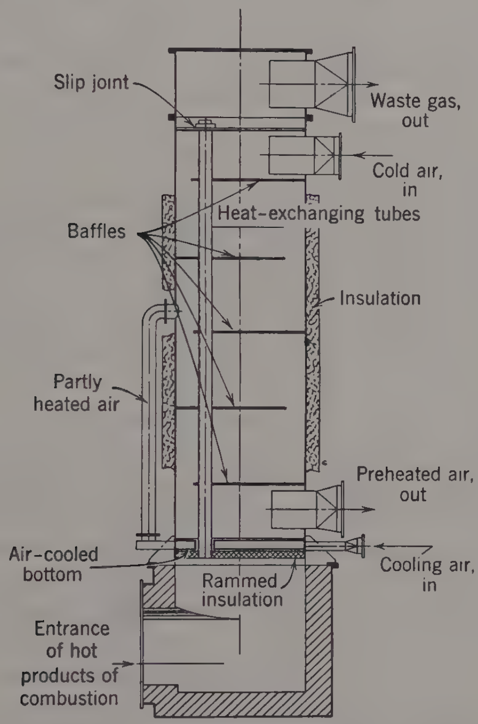

FIG. 280. Detached recuperator for large furnaces. Suitable for dust-laden products of combustion.

Heat salvage by brick-filled regenerators is the rule with blast furnaces and with furnaces in which steel or glass is melted. Regenerators were invented, not for heat salvage, but for raising flame temperatures. In the heating of solid metals, the application of regenerators is very limited. Before 1930, regenerators were standard equipment for pit furnaces (soaking pits). Such furnaces are now equipped with recuperators. Furnaces that heat heavy blooms and forging billets of varying size and weight are the best field for the use of regenerators. In forge furnaces for heating high-carbon steel, the

economy secured by heat salvage in regenerators is to a large extent imaginary because the whole furnace, including the regenerators, must be cooled down after each heat for the purpose of avoiding injuries to the cold ingot which is to form the next heat. Here a much simpler type of furnace will do just as well or better. If heat economy is to be secured by the regenerative system, the steel must be preheated beyond the range of blue brittleness in a separate preheating furnace. With soft steel, such as structural steel, preheating is not necessary, and the steel can be put into the hot furnaces. If a regenerative furnace is to be made automatic with regard to temperature control or atmosphere control, a great deal of equipment is necessary.

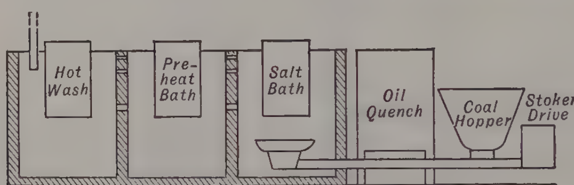

FIG. 281. Stoker-fired salt bath, with utilization of waste heat.

Heat salvage in waste-heat boilers is discussed in Volume I. The discussion may be summarized in the statement that waste-heat boilers do not pay dividends unless the steam can be utilized at or near the furnace, for instance in a steam hammer or for atomizing liquid fuel such as oil or tar. In large forging establishments with many furnaces the labor cost of attending the scattered waste-heat boilers greatly exceeds the cost of the fuel that can be saved by waste-heat boilers (sad but true). Rapidly rising costs of labor have changed the picture from what it was thirty years ago.

An interesting example (that does not fit into any classification) of heat salvage is illustrated by Fig. 281.

Method of Heat Transfer. Furnaces can be compared with regard to the method of transfer of heat from the source of heat to the charge, and by this method of classification can be divided into three groups. In one group the heat is transferred from the heating medium, whether it be products of combustion or electrical resistors, directly to the charge, no wall intervening. This type is frequently called the direct-fired type, or the open-chamber type, or the oven type, or the unmuffled type, or a box furnace. In the second class of furnaces heat is transferred to the charge through a muffle, that is to say, through a separating wall; the separating wall may surround the charge and is then called a muffle. If the separating wall surrounds the flame,

it is called a radiant tube. In some furnaces, double protection is obtained by enclosing the charge in a muffle and by the use of radiant tubes. Salt baths and lead baths surround the charge and take the place of muffles. In a third group, heat is generated in the charge either by resistance heating or by induction heating.

If products of combustion and the charge are in the same chamber, without an intervening partition, heat is transferred by radiation and by convection. Radiation predominates at high temperatures. In ovens (below 1000 F) convection predominates. Electric resistors transmit heat mainly by radiation, at least at high temperatures.

From test data and from calculations in both volumes it is known that hot products of combustion transmit heat not only to the charge, but also to the roof and to the sidewalls of any furnace and that the walls radiate that heat back to the charge. This method of heat transfer (direct heating) requires the least expensive furnace and is used whenever the heating stock is not seriously damaged by contact with the products of combustion. Direct heating is also employed for temperatures that are so high that neither muffles nor radiant tubes would be durable. At temperatures of 1800 F or higher, steel is not only oxidized but is also decarburized. Since both of these actions are functions of time and of temperature, very rapid heating reduces oxidation and decarburization. Heating is rapid if combustion takes place in an extremely short time, before the products of combustion give up their sensible heat to the walls and to the charge, and if so much fuel is burned that the products of combustion leave the furnace with a temperature that lies far above the temperature to which the charge is to be heated. High-speed heating or high-temperature-head heating, as it is often called, not only reduces scaling and decarburization, but it also results in a smaller and (supposedly) less expensive furnace. Among the disadvantages of rapid heating are high fuel consumption, and the necessity of quick action in case of interruptions in the processing of the heated material. The multiplicity of burners required for rapid heating is shown in the line drawing Fig. 147 and also in the photograph Fig. 282. Some of the barrels forming an "in-line" furnace of the type illustrated by Fig. 146 are shown in greater detail in Fig. 283. The advantages of high-speed heating are recognized, but it has limitations. Large pieces of some steels cannot be heated rapidly without the formation of cracks. They are the steels that have a low thermal conductivity below red heat and that are still hard at red heat. The minimum safe heating time for steels of various compositions and sizes is given in *Industrial Heating*, June 1954. Ingots require a longer heating time than is needed for

forged or rolled blooms of corresponding size and having the same composition.

Heat Transfer by Convection. Furnaces in which temperatures below 1000 F prevail are more properly called "ovens." In ovens, heat is transferred to the charge mainly, but not entirely, by convection. A clean fuel is burned in a separate combustion chamber

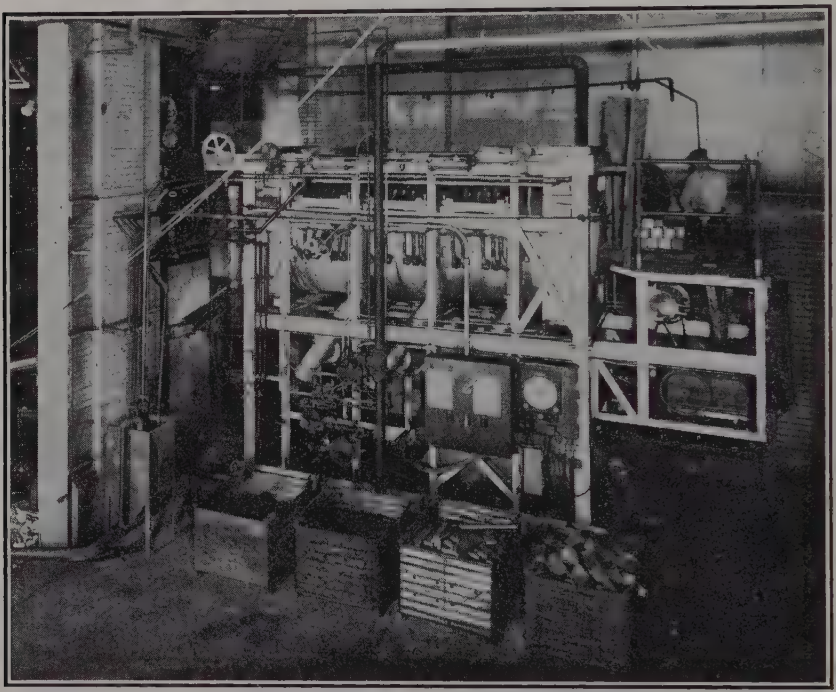

Fig. 282. Continuous pusher-type furnace for rapid heating of forging billets. Note the large number of burners.

through which gases coming from the oven are recirculated by a fan. Ovens of this type are sometimes called "air furnaces." It is important that the recirculated oven gases contact the whole surface of the charge. To this end various means are employed that depend on the shape of the charge. Among such means are baffles, heat ports, and apparatus for rotating the pieces of the charge. As previously explained, rapid heat transfer by convection requires a high velocity of the gases; high gas velocity is obtained by high blower capacity. Heating is then brought about not only by Btu, but also by horsepower. The occasionally encountered rule that, for good heating, the oven gases must pass eight to ten times over the pieces of the charge

is unsound, because the velocity of the oven gases, which has an enormous influence, does not appear in the rule. Convection heating by recirculation is employed for furnace temperatures up to 1400 F.

Heat Transfer by Conduction. Heat is transferred principally by conduction in salt baths and in lead baths, because of the great density of the molten materials in the baths. The liquid salt or lead freezes

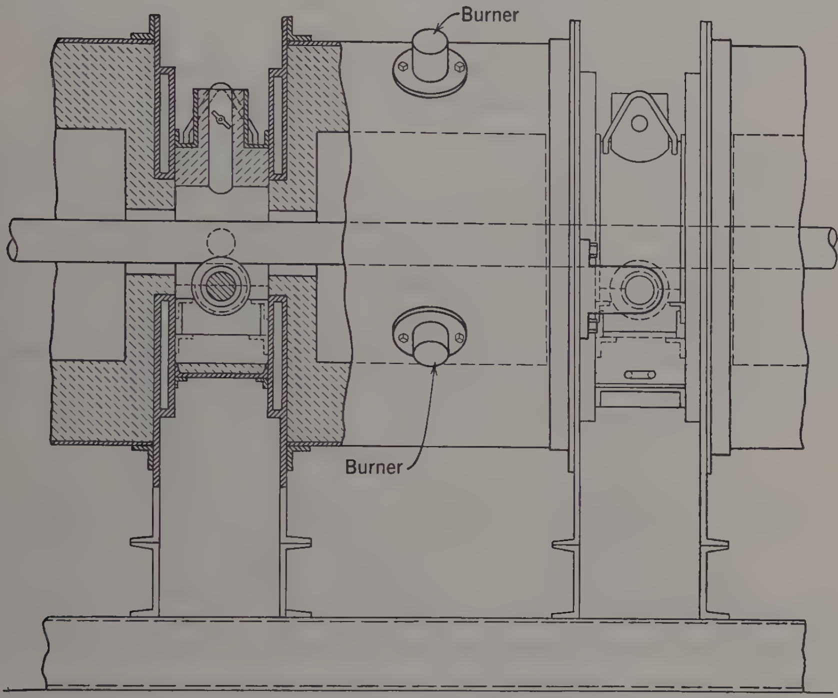

FIG. 283. Barrels for in-line furnace for high-speed continuous heating.

on the cold charge, but is rapidly thawed off by conduction and convection. Freezing of the salt tempers the thermal shock. Nevertheless, heat transfer is so rapid that large pieces of a tender steel are preheated to about 700 F either in products of combustion or in a salt bath that is molten at that temperature.

Salt-bath furnaces and lead baths are used because the bath acts like a muffle and excludes the atmosphere and, also, because heat enters uniformly from all sides. One effect of the high rate of heat transfer by conduction is that the bath has practically the same temperature as the heated charge has. Overheating is impossible, no matter how long the charge stays in the bath, unless the bath tem-

perature is too high. Thick and thin pieces can safely be heated in the same bath at the same time.

In cyanide baths the above-mentioned advantage that time in the bath makes very little difference is lost. Time, temperature, and composition of bath determine the depth (the case) to which a heated steel piece can be hardened. This fact is illustrated by Fig. 284 for a cyanide bath of average composition.

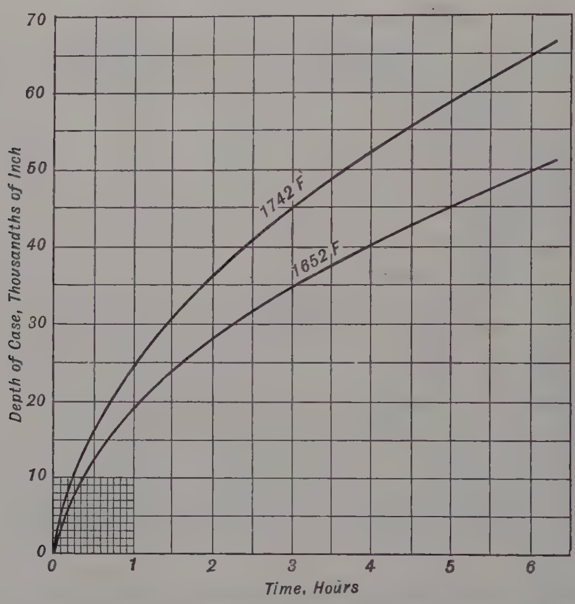

FIG. 284. Time-temperature-penetration curves for salt baths. Courtesy of *Iron Age,* July 4, 1940.

Salt baths and lead baths can be compared to other methods of heating with regard to both method of heat transfer and selection of furnace atmosphere. For that reason, their field of usefulness may well be discussed right here, under the heading of heat transfer. Bath furnaces are especially useful in precision heating of articles of a great variety of size and of thickness. Although salt baths are occasionally applied to the heating of heavy objects, their greatest field of application lies in the heating of objects that can be handled by man power. Bath furnaces are ideal for the job shop; they have been replaced by furnaces of other types in mass production. The question, "What costs more, heating with formation of scale or heating in a protective atmosphere?" (which term includes salt baths) is discussed in a later section of this chapter.

The upshot of the discussion on methods of heat transfer is this: Direct transfer of heat from products of combustion, mainly by radiation and partly by convection, generally results in the simplest and least expensive furnace. Heat is transferred in this manner, whenever the formation of an oxide skin (scale) either does no harm or else is welcomed for the removal of surface blemishes. In an overwhelmingly great majority of furnaces steel is heated for rolling and forging in products of combustion. Exceptions are noted in earlier chapters. For lower and lower furnace temperatures, radiation is supplemented more and more by convection. Around 1200 F convection takes over. In ovens, heat is transferred by convection, which is supplemented by radiation. As previously explained, recirculation and direct circulation by excess air are the principal means for securing temperature uniformity in convection furnaces. In low-temperature furnaces that are heated by radiation (electric resistors or radiant tubes) fans are installed above and below the charge for the purpose of transmitting part of the heat by convection. Heat transfer by conduction is now limited to lead baths and to salt baths. Experimentally, tinplate strip is being annealed in a liquid of high conductivity. The process is not yet in commercial use.

Muffle furnaces are now seldom seen. Radiant tubes (flame in muffle) are now very common. They are used in the same manner as electric resistors are used.

Method of Heat Application. In a comparison of the different methods of heat application a distinction must be made between partial heating and total heating.

Partial Heating. Generally, partial heating is applied to the end or ends of a bar or a tube. Examples are heating for upsetting and other forging operations for nosing of shells and of bombs. At other times a length near the center of the bar is heated. In partial heating uniformity of temperature is out of the question, because the temperature tapers off from the heated portion to adjacent cooler portions. It is, however, desirable to have in the heated portion a temperature distribution that is suitable for the process that follows the heating. One problem in partial heating is to heat so quickly that very little heat can flow into the unheated part, and yet to avoid troubles that might arise from heating too rapidly. In most practical cases the second part of the problem does not exist.

When the hot end of a bar is forged "off the bar," a sharp line of demarkation between hot and cold is not needed, because any heat that flows into the cooler portion is utilized in the next heating of the bar. Most furnaces serving this purpose are very simple, as

shown in Fig. 285. The dotted lines indicate the position of the last end of the bar. Only enough metal sticks out to offer a tong hold. Oil firing is very common. The bar ends are brought up to a white heat, so that the bar drips steel on the way to the hammer or the press. The steel is free from scale when entering the die. Naturally, slag is formed in the furnace, which is equipped with a slag hole. This method of heating gives the impression of being medieval, but it works.

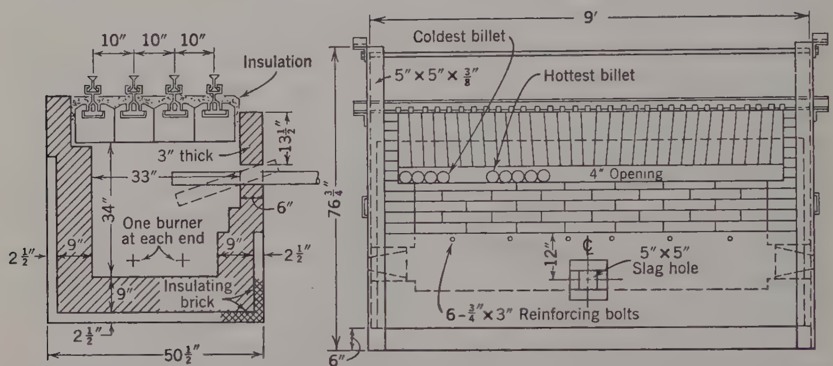

FIG. 285. Partial heating in furnace without a hearth for supporting the charge.

Frequently the process that follows heating requires a reasonably sharp line of demarkation between hot and cold portions. Examples are the nosing of artillery shells and the forging of the noses of demolition bombs. A simple method consists in dipping the piece into a salt bath as far as it is to be heated. The line of demarkation is indeed very sharp, but the adhering salt corrodes the conveyor that leads to the nosing press. For this reason this otherwise good method is seldom employed.

A sharp line of demarkation is also obtained if the extreme end of the piece is heated first and if heating is gradually extended to the final, desired length. For this purpose several means are in existence. The piece to be heated, for instance a rough-machined artillery shell, may gradually be moved into the furnace either manually or automatically. The latter method is illustrated by Fig. 286. The whole nosing furnace rotates; each shell is gradually shoved into the furnace by a stationary cam. The shells are being rotated around their own axes while exposed to heat. In another method for accomplishing the same purpose, shells are set vertically into sockets of a conveyor chain and are rotated while passing through the furnace. The shell blanks

are flanked by (vertically) contoured walls that control the length to which heat is applied.

A fairly sharp line between hot and cold sections may be obtained in several different ways. Fig. 287 illustrates a furnace for heating the ends of seamless tubes. Each tube rests in a water-cooled bushing. A refractory stopper prevents flow of gases through the tube.

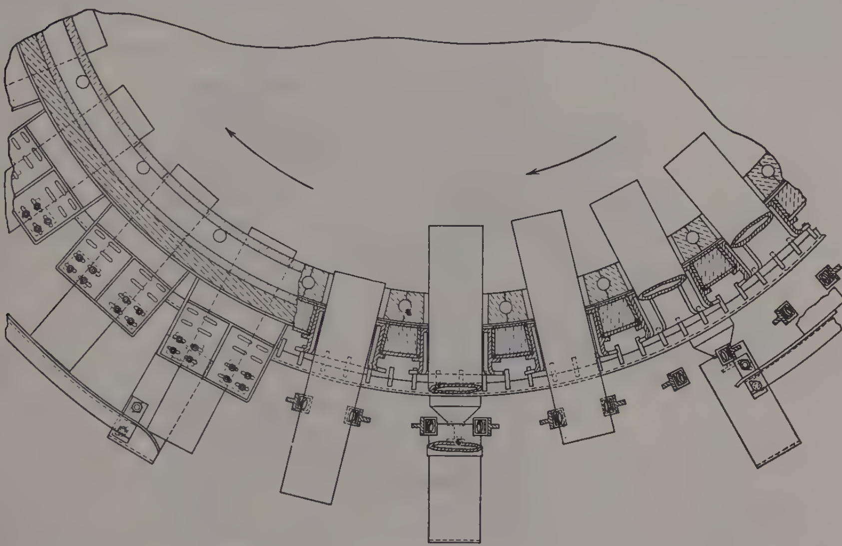

FIG. 286. Rotating furnace with automatic gradual shoving of charge into furnace.

In mass production, partial heating is often carried out by means of induction. The tube end shown in Fig. 287 may be heated by an internal induction coil and be processed in place after the coil has been retracted.

Partial heating near the central portion of a bar or tube is frequently called "local heating." Such heating is accomplished either by a multiplicity of blowtorch burners or by induction. Local heating is used for hardening by quenching. A furnace is not necessary. In many cases it is a hindrance. The correctness of this statement is apparent from a study of Fig. 288, which shows local heating by high-frequency current followed by quenching in place. This method of hardening has been widely adopted for mass production.

Total Heating. When total, or overall, heating is practiced, the intention is to bring the heating stock up to a uniform temperature. Furnaces for total heating can be compared with regard to the methods of heat application and a study can be made of those types which,

in the simplest manner, produce a uniform temperature in the charge.

Without any doubt, suspension of the work within the furnace or within the salt bath results in the most uniform application of heat. However, suspension is limited by furnace temperature and by weight of heating stock. At 1600 F fairly heavy pieces, such as groups of artillery shells or even container tanks, can safely be heated in suspension. At 2300 F, heavy pieces are not heated in suspension,

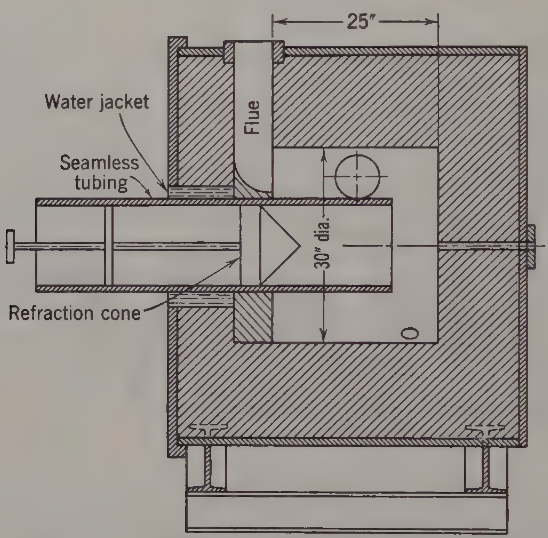

FIG. 287. Furnace for heating the ends of tubes.

because the hangers would be stretched and probably be torn during the long heating time. In a batch-type furnace, in which several pieces are to be heated simultaneously, several holes would have to be made in the roof. Engineers shy away from heating heavy objects in suspension to temperatures above 1600 F, for fear of losing their jobs or their reputations or both. From Chapter V it is known that medium-weight objects are heated continuously in suspension to 2300 F. It is also known that very special and ingenious methods were provided in order to make suspension heating a success at high temperatures. In salt baths the heating stock is lighter and the heating time is reduced. For both reasons salt baths lend themselves to heating suspended objects. Conveying the charge on a chain belt with heat above and below the belt approaches the ideal condition.

From the standpoint of heat application the next best method consists in supporting the heating stock on piers or pedestals which are

sufficiently high and thin to allow heat to be applied freely from all sides. Height, thinness, and material of the piers are limited by furnace temperature and by weight of the charge. Piers of cast iron and of steel are very serviceable for temperatures below 1650 F. At higher temperatures oxidation wears them down rapidly. They also sag on account of low creep strength. Tall and thin piers of silicon carbide (if obtainable) are sturdy and strong at high temperatures, but are eaten away by molten iron and by molten scale. Tall supports of even the best firebricks are knocked down during charging

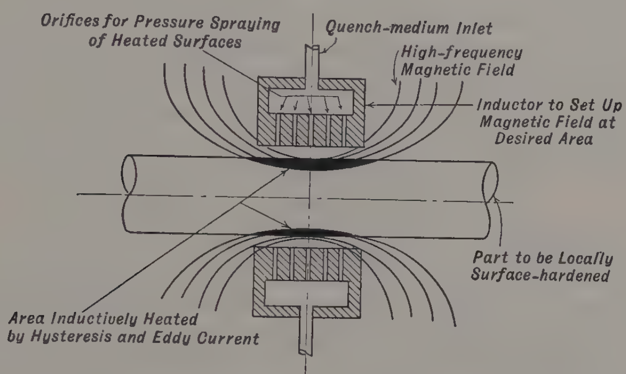

FIG. 288. Principle of induction heating and quenching by same equipment.

and discharging. The upshot is that, for temperatures above 1650 F, low ledges or ridges of firebrick are preferred. In spite of the small elevation above the hearth, heat application is reasonably uniform if the pieces that form the charge are laid so far apart that heat radiated from the products of combustion and from the roof to the hearth can be reradiated to the under side of the heating stock. At temperatures below 1400 F, radiation is weak and combustion gases are projected into the space below the charge.

Heat application is uniform, if a cylinder or a prism is set on end upon the hearth. If the length of such objects exceeds three times the diameter (or short side), the danger of toppling over becomes uncomfortably great. If one piece is accidentally knocked over, many other pieces tumble, and the labor of setting them up again is not only expensive, but also interferes with uniformity of heat application.

At this point it is appropriate to realize that uniform application of heat does not necessarily result in uniform temperature in the heating stock. This statement refers particularly to heating stock of rectangular (or square) cross section with sharp corners. Uniform appli-

cation of heat to such bodies causes higher temperature in the edges and in the corners than in the flat surfaces. In rapid heating, the edges, and even more so the corners, are melted before the bulk of the charge has been brought up to temperature. This statement refers to large pieces.

Application of heat from one side only is common in many furnaces of the pusher type. Uniformity of temperature is approached, but not realized, by a long heating time, the length being determined by the linear dimensions of the heating stock, as explained in Volume I. If the furnace temperature equals the desired final temperature of the heating stock, uniformity of temperature is reached after an infinitely long heating time. The practical solution of the problem (if one-sided heating is insisted upon) is found in very rapid initial heating which is followed by soaking in a separate zone. In the soaking zone the temperature should exceed the final temperature of the stock by very little; for most uniform heating, the temperature may even be slightly below the final temperature of the charge.

One-sided heat application is seldom encountered, if billets more than 4 in. thick are pushed through a furnace. Heat is applied from top and bottom to billets of larger sizes. Even with two-sided heat application the principle of rapid initial heating and of soaking in a zone of lower temperature is correct. Rapid initial heating is obtained by side firing above the billets. Side firing under the billets is possible, but difficult. Another method of securing rapid initial heating consists in firing a continuous furnace from the cold end, where the stock enters. Fig. 289 shows the method of firing and the temperature distribution in the charge. In spite of the advantages of side firing and of reversed firing, these methods have not taken root in the United States. Correct heat application and fuel economy do not go hand in hand in either one of the two methods of heat application.

In the study of heat application the terms "underfired, sidefired, and overfired" must be discussed. Underfiring means that the fuel is burned below the charge, that is to say, below the hearth. The purpose is to get away from a cold hearth. As proved in Volume I, the hearth in underfiring is warm, but not hot. The principle of underfiring alone is no guarantee for correct heat distribution. The products of combustion, coming up from the combustion chamber, must be led uniformly through the heating chamber in such a way that no "hot spots" are produced. The principles which must be employed in guiding the gases properly, for the purpose of producing greatest uniformity in heat application, are discussed in Volume I, under the heading Movement of Gases through Furnaces. If underfiring is com-

bined with recirculation, as indicated diagrammatically in Fig. 290, good uniformity of temperature distribution is obtained. The energy of the flame jet inspirates gases from the heating chamber. Unfortunately, the circulation is least active when most needed, that is, at low rates of firing. Circulation is quickened by blowing in excess air, either through the burner or through a separate nozzle.

So-called "side firing" involves the existence of a bridge wall which breaks the impact of the flame and directs the products of combus-

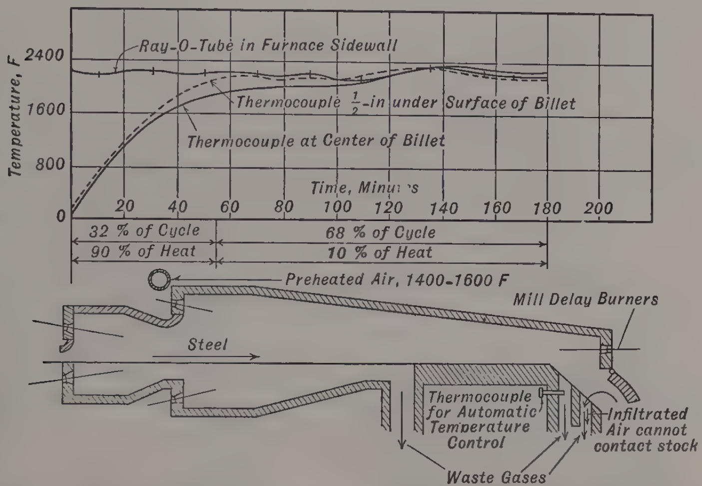

Fig. 289. Continuous furnace, fired from the entering (cold) end.

tion. This latter function the bridge wall should perform in such a manner that it distributes the heat uniformly throughout the heating chamber in spite of the one-sided arrangement of the combustion chamber. If the bridge wall is tall, circulation alone does not produce uniformity of temperature, and the bridge wall is perforated in certain spots; moreover, its height is not constant along the length of the furnace.

The bridge wall and the openings in it are clearly shown in Fig. 291, which represents a stokerfired annealing furnace with two combustion chambers side by side. The path of the products of combustion and the manner in which they are intended to circulate, for the purpose of giving uniform heat distribution, are clearly shown in the illustration. In some designs the bridge wall is made, at least in part, of silicon carbide, for the purpose of transmitting radiant heat to the corner (of the heating chamber) which is more or less dead so far as furnace-gas circulation is concerned.

A sidefired furnace with oil as fuel is illustrated in Fig. 292. In this furnace, also, provision was made for uniform distribution of temperature over the whole hearth as far as uniformity could be obtained with a cold bottom. More than any other type, the sidefired furnace depends for its success upon proper circulation of the gases, which in turn depends upon proper velocity of the incoming fuel or products of combustion, proper distribution of the inlet ports, proper space above the bridge wall, and proper distribution of the outlet ports. These details are discussed in the chapter on Movement of Gases in Furnaces, Volume I.

If salt pots or lead pots are to be oilfired, side firing is often resorted to, as

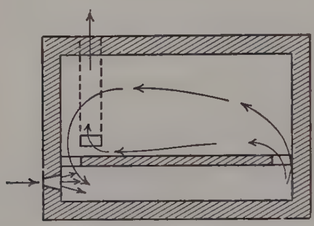

Fig. 290. Underfired furnace with recirculation of gases induced by jet of flame.

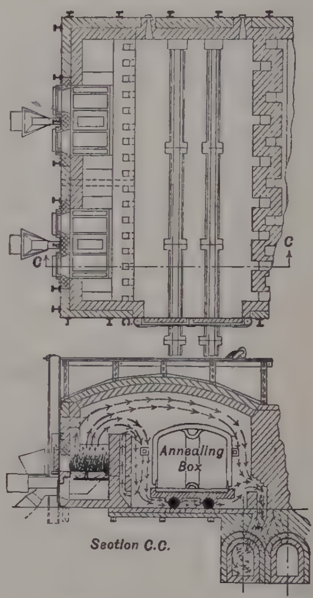

Fig. 291. Stoker-fired annealing furnace, sidefired type. Note design of bridge wall.

shown in Figs. 293 and 294. The former shows the side firing of a small pot, whereas the latter shows the side firing of a pot which is 24 in. deep. The products of combustion enter the heating chamber tangentially near the top. If they entered near the bottom, the pot would burst when heat is applied after a complete shutdown.

The term *overfired furnace* is commonly applied to that type in which a perforated roof or arch is interposed between the combustion chamber and the heating chamber proper, as shown in Fig. 295. The combustion chamber lies above the heating chamber. The overfired furnace is used almost entirely with oil firing. Overfiring is designed to meet the conditions created by oil firing, its purpose being to secure a uniform temperature distribution over the hearths of furnaces working with temperatures of 1200 to 1400 F. This advantage is obtained at the expense of fuel economy because the large combustion chamber dissipates much heat, unless it is constructed of superduty refractories and is well insulated.

Underfiring, side firing, and overfiring are remainders left over from the early days of oil firing. Strainers and filters were poor; small burners were clogged and choked up. This fact was a good reason

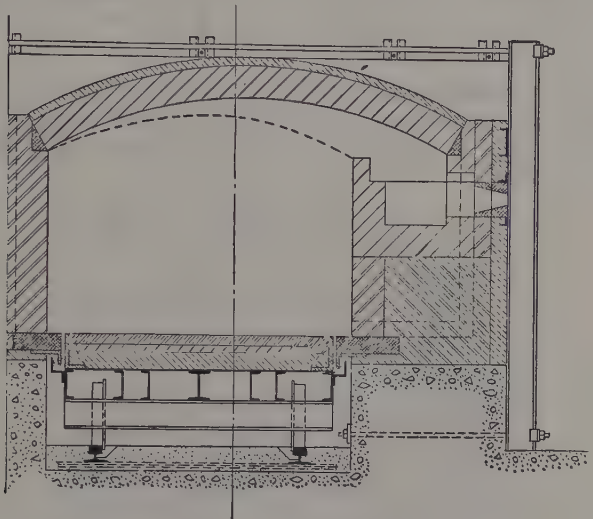

FIG. 292. Sidefired car-type furnace for fuel oil. A number of combustion chambers are arranged on one of the long sides. In front of each chamber is a bridge wall of varying height.

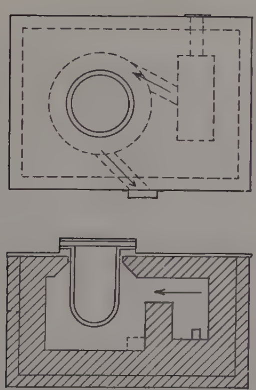

FIG. 293. Small side-fired pot furnace.

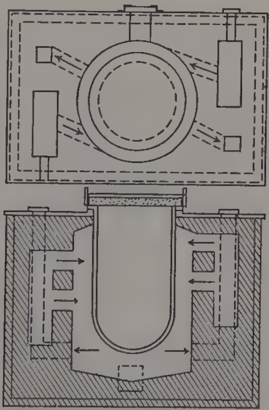

FIG. 294. Deep pot furnace, sidefired on two levels.

for the installation of a small number of large burners that required special furnace designs for making temperature distribution uniform. Small particles that would clog a small burner readily pass through

a larger burner. In addition, furnace operators prefer a small number of burners, because the small number of burners reduces the number of adjustments that have to be made. A few large burners and their piping cost less than many small burners and their piping. However, the construction of furnaces with underfiring, side firing, and overfiring is fairly expensive.

The foregoing paragraph is not intended to convey the impression that many small burners necessarily result in a uniform temperature of the charge. If a few large pieces are to be heated, for instance for

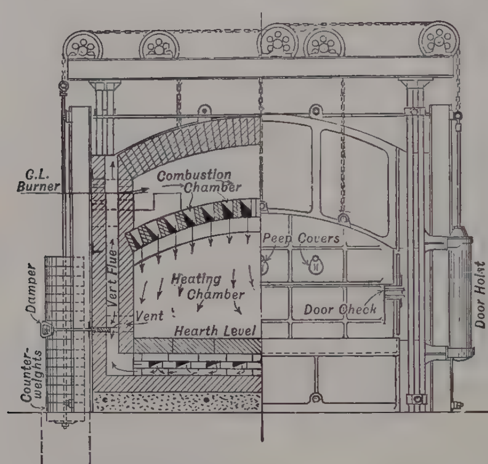

Fig. 295. Overfired furnace, oil fuel.

the purpose of annealing, the burner adjustment should differ from the adjustment that is best for heating pieces of different size and shape. In the heating of a large object inexperienced or negligent operators may fail to adjust the burners to the new condition, and hot spots will occur in the charge. In some materials hot spots do little harm, but in other materials, such as rolls for rolling mills, hot spots become soft spots, and the rolls are rejected by the customer or are not even delivered to him. A few large burners properly located to cause a swirl cannot be misadjusted. Again, a few large burners do not assure uniform heat application. For uniformity, the charge must be elevated above the hearth, well-distributed vents must be provided near or in the hearth, and excess air may be blown in so as to lower flame temperature.

Underfiring is not always employed for the purpose of securing temperature uniformity by means of a hot hearth. Fig. 296 illustrates a coal-fired furnace that was developed at a time when a coming

shortage of fuel oil was predicted. The combustion chamber for powdered coal lies far below the hearth and cannot possibly transmit any heat up through the hearth. The underground chamber serves for complete combustion of the coal and for depositing ash. Heat cannot escape through the walls of the underground chamber; in consequence, adiabatic flame temperature prevails in that chamber. Adiabatic flame temperature is 4100 F for coal burned with the theoretical volume of air preheated to 500 F. With 30 per cent excess air the temperature still reaches 3400 F. No reasonably inexpensive refrac-

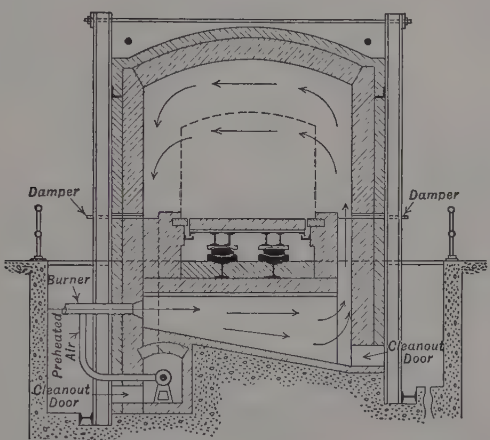

Fig. 296. Underfired car-type furnace using powdered coal.

tories can withstand these temperatures and the effects of ash. When the design of Fig. 296 was published, it was heralded as a great achievement in engineering (a ten strike). Soon afterwards, matters became very quiet and the achievement fell into oblivion. It is cited here as a horrible example.

It is impossible to arrange furnaces of all types in a classification. Furnaces are in existence that are both sidefired and underfired. And classifications do not stay put. An example is the term "direct-fired." For many years the term meant that combustion took place in (or at least extended into) the heating chamber. In the 1950's it acquired an additional, somewhat different meaning: When sheets were annealed under a light and tight cover that was heated on the outer side by radiant tubes, the words "direct firing" still had their original meaning. But when it was discovered that there was very little difference in cost between burning out inner covers and burning out radiant tubes and that patent rights could be circumvented by flames between

the inner and outer covers, the method of heating the inner cover by products of combustion was called "direct firing," although the products of combustion do not enter into the space where the charge is being heated. The controversy "radiant tubes or direct firing" is still very much alive at the time of this writing (1954).

An earlier section contains the statement that uniform application of heat does not necessarily result in uniform temperature within the charge. A characteristic example is the heating of strip sheet in coils. Fig. 297, which was adapted from an advertising picture, illustrates the statement in a crude manner. (Material as thick as shown

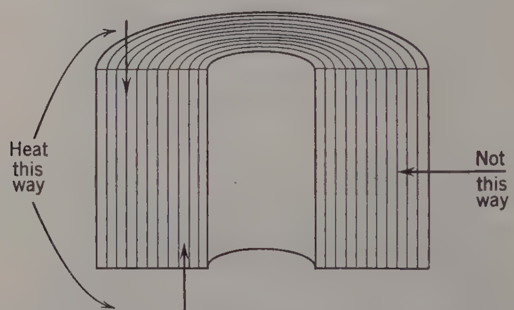

Fig. 297. Methods of applying heat to coils of strip.

in Fig. 297 could not and would not be coiled.) Heating from the ends is easily accomplished if the coils move through the furnace on a roller hearth. If heat flow is to be the same in all layers of the coil, the latter should be surrounded by an insulating cylinder. Cooling the coil takes more time than heating does.

Heat Generated within the Charge by Electrical Energy. This method of heat application (if it can be given that name) is explained in earlier chapters. In the present chapter the discussion deals with the question: Under what conditions is generation of heat within the charge more advantageous than external application of heat? With regard to partial heating the question is discussed earlier in this chapter. Total heating of bars that serve as resistors is discussed on page 124. Total heating of bars by induction is very convenient and labor saving for bars that can be handled manually, that is, bars up to about 3 ft in length. Fig. 298 illustrates the ease with which such bars are handled. At the end of its heating time each bar is automatically pushed out of its coil and is then grabbed by pinch rollers that deposit the bar on a peel. From there the attendant swings the bar around to a press or a hammer. No actual lifting is needed. The advantages are obvious. There is practically no scal-

ing. Heating always occurs within the same span of time. The workroom is clean and cool. But induction heating also has disadvantages. Among them is the high cost either of the equipment for generating high-frequency current or of capacitors if heating is done by low-frequency current. Bars of different cross-sectional area or

FIG. 298. Induction-heated bars are automatically removed from furnace.

of different shape and length require different coils, unless the differences in dimensions are very small. Correct winding of new coils requires experience to guard against uneven heating of the ends. And finally, induction heating shares with all other forms of electric heating the high cost of energy.

In the heating of large pieces such as 8-in. rounds or 7-in. squares, some of the advantages of induction heating become very small and only one of the disadvantages is reduced. Induction heating of 7-in. squares requires from 17 to 25 minutes depending upon the rate of

energy input. In that time scale is formed. Horizontal heating of heavy billets runs into trouble with the supports and with the mill scale that drops off. In vertical heating sheared billets lean over to one side and almost melt on the side that is closest to the coil. The billets must be held central and vertical by strips of heat-resistant steel. Transportation, by crane, of heavy billets to the heating cells and from them to the press, hammer, or rolling mill is very troublesome, unless a soaking-pit crane has been installed. And if the billets are to be laid down horizontally in the press or hammer, a soaking-pit crane with a manipulator attachment is needed.

Contrariwise, the first cost of equipment for induction heating of large objects is relatively much smaller than it is for heating small objects, because line current of 60 cps serves very well. This fact was first applied commercially in the early 1940's, but was publicized only recently (1953). In the fall of 1953 the West Penn Power Company for several weeks ran demonstration tests in Uniontown, Pennsylvania, for the purpose of convincing owners of forge plants and of rolling mills that steel can be successfully heated with 60 cps current. Table XVIII summarizes the results of tests that were made in the presence of the author.

TABLE XVIII

Material, steel	Dimensions, in.	Average Final Temperature, F	Heating Time, min	Power Factor, %	Kw-hr/ton
0.40% C	8×8×35	2200	18	60 to 30	288
0.40% C	6×18×32	2190	31.5+10.5*s**	56 to 26	279
Stainless	6×18×30	2090	31+20*s*+6+3*s*	25.5 to 22	271
Stainless	12×12×30	2240	48+9*s*	48 to 22	305

* The letter *s* after a time signifies soaking time in the coil. Unless the coil is lined with a refractory, soaking accomplishes no useful purpose because the water-cooled coil absorbs heat. In the third billet, the temperature distribution was far from being uniform. The temperature ranged from 1870 F to 2270 F.

The General Engineering Company, who cooperated with the West Penn Power Company during the tests, furnished the following approximate information on first cost, as of 1953:

High frequency with motor-generator frequency converters:
$150 to $200 per kw, $60,000 to $80,000 per ton of hourly capacity.
Dual frequency, 60 cps plus some higher frequency:
$60 to $100 per kw, $20,000 to $30,000 per ton of hourly capacity.
All 60 cps: $30 to $50 per kw,
$10,000 to $15,000 per ton of hourly capacity.

These figures include frequency-converting equipment, where needed, power factor correction, switching, coils, and fundamental handling

equipment. They do not include any substation requirements. If material of different sizes is to be heated, the cost of additional coils must be added.

The company recommends "all high frequency" for sizes below 1¼ in. sq, dual frequency between 1¼ and 6 in. sq, and low frequency for all sizes above 6 in. sq.

Induction heating is so rapid that formation of scale is reduced. It may be repeated that formation of scale is purposely brought about in many cases.

Examples of Heat Application. In many instances the method of heat application is influenced or even determined by the processes that precede and follow the heating operation. The pit furnace or soaking pit is a good example for this statement. In regular operation the pit furnace does but little heating because, if everything goes right, the center of each ingot is hotter than needed, whereas the outside is too cold, especially at the edges. An old rule states that heating time in the pit furnace should equal track time. The latter expression means the time between pouring of ingot and charging it into the pit furnace. Any delays ahead of the pit furnace or beyond it increase the track time; the ingots become dull red, or sometimes even stone cold. In spite of these variations the pit furnace is expected to furnish ingots that have a reasonably uniform temperature from top to bottom and a very uniform temperature around the circumference.

A seemingly ideal way of heat application would be to lower each ingot into a separate individual cell and to heat that cell by means of many small burners. Individual cells were installed in Germany before the turn of the century, but the method of heat application was crude. In the United States large pits, holding up to 12 ingots, were installed. They were disdainfully called "common graves" ("massengrab" in German, "fosse commune" in French) by the Europeans. The problem in connection with the large pits is how to apply heat in order to deliver the ingot with a temperature uniformity that is acceptable to the superintendent of the blooming mill. The flames are very hot, except when blast-furnace gas is the fuel. Although the required flame temperature can be reached with cold air in the combustion of rich fuels, air is usually preheated even with these fuels, for the sake of fuel economy.

A number of different heat applications are illustrated by Fig. 299. Some of them overheat the top, others overheat the center, and still others overheat the foot of the ingot. A temperature variation up to 100 F or even 125 F between top and bottom of an ingot does very little harm, because modern blooming mills are strong enough to pro-

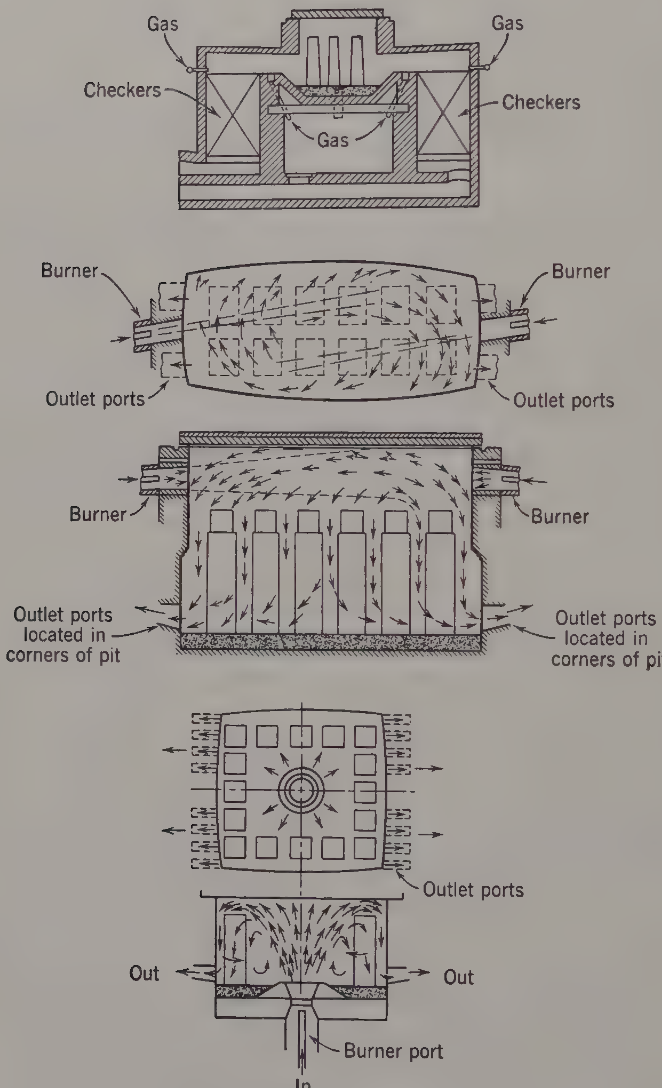

Fig. 299. Methods of heat application in pit furnaces.

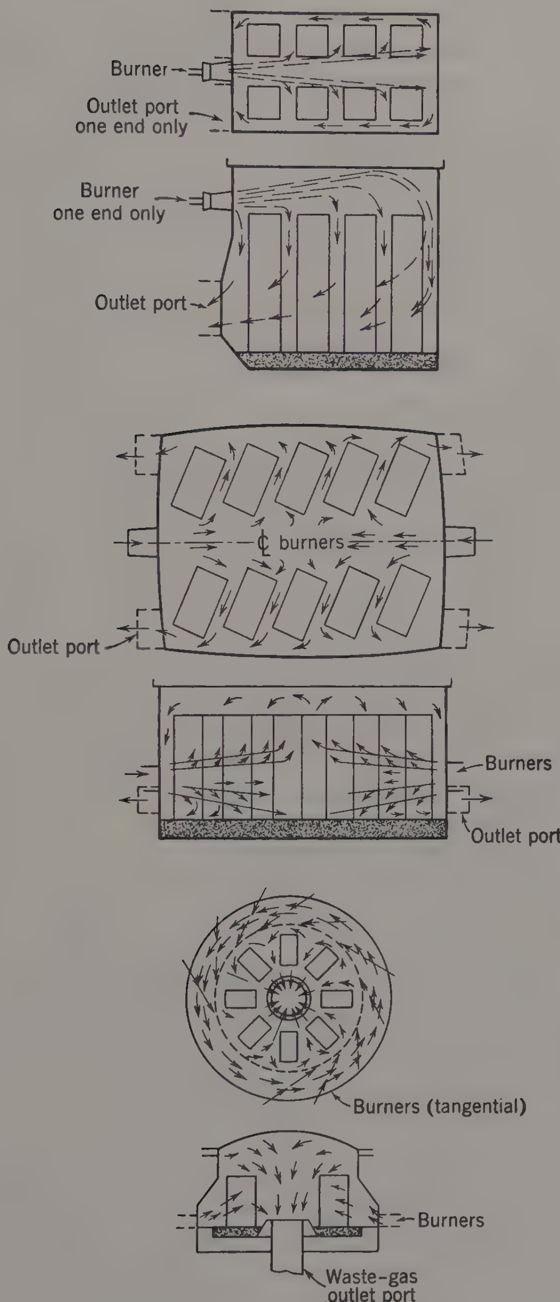

Fig. 299 (*continued*).

duce blooms of uniform cross section in spite of temperature variations along the axis. Temperature differences around the circumference are more harmful. If the cold side of the ingot is at the bottom, the bloom bumps each table roller and induces breakage. If the cold side is on top, the bloom tends to curl up around the top roll. Of course an experienced roller knows how to mitigate the results of uneven heating, but he cannot prevent the curving of the bloom. A curved bloom after edging is correctly entered into the pass with difficulty only. Realization of the facts cited above has led to the abandonment of a once-common practice, which consisted of leaning the ingots against the walls of the pit.

A study of Fig. 299 reveals the shortcomings of the various methods of heat application. Heating from the top and venting near the bottom appear to produce sufficiently uniform heating, unless the ingots are set too close together. Unfortunately, no vents can be arranged directly in the bottoms of soaking pits. In Europe, many modern pit furnaces are equipped with several sets of burners in vertical alignment. One set fires clockwise, whereas the other set fires counterclockwise. They are reversed at regular intervals.

Since 1952, electrically heated pit furnaces have been installed in several European countries, especially in those countries which enjoy inexpensive water power. The heating elements are silicon carbide troughs; they are filled with petroleum coke. Scale formation is less than 10 per cent of the scale formed in fuelfired pits. At this writing (1955) efforts are being made to introduce electrically heated pits in the United States.

Methods of Handling and Conveying. The equipment for moving objects into, through, and out of furnaces is described in Chapter V. In the present chapter an answer is sought to the question: What method of handling and conveying is best for a given set of conditions? In very general terms, the answer is simple: That handling device which (without interfering with good heating) results in the lowest sum of interest, depreciation, operating labor, and maintenance labor. In many cases the selection is difficult, whereas in other cases the decision is easily made.

Quite obviously, furnaces in which light objects of different sizes and shapes are to be heated to various temperatures must be of the batch type and need no handling device except a pair of tongs. If, under otherwise equal conditions, the heating stock is too heavy to be moved by direct muscular effort, a lever is installed, the fulcrum of which is either suspended from a monorail or else is supported on a buggy. The long outside arm is moved manually; the short arm

reaches into the furnace. As explained in Chapter V, gripping is accomplished by a toggle joint. A necessary piece of equipment is a trough of water into which the hot end of the lever is dipped between operations. The statements of this paragraph also apply to salt baths, they being likewise well adapted to heating objects that vary in size and shape. In the heating of various objects for quenching, the general-utility furnace illustrated in Fig. 169 renders good service. It is furnished complete with handling devices.

At the other extreme are manipulating devices for ingots and heavy blooms that are heated to 2200 F or 2300 F. If these heavy objects vary in size and are to be processed under a press or a hammer, a group of batch-type furnaces is installed, which are served by a charging machine. The latter may travel on rails and lay the billet on a roller table, or it may be of the universally mobile type which takes the billets out of the furnaces and delivers them to the hammer or the press. If the furnace charger serves as manipulator during the forging operation, additional equipment must be installed for charging if the press is to be operated without interruptions. In rolling mills, heavy and long pieces of rectangular cross section and even small ingots are pushed through furnaces. The pusher does the conveying. If a furnace is of the gravity-discharge type, no additional equipment is needed except a device for interlocking the movements of the discharge doors and of the pusher. In furnaces with side discharge, a discharge pusher is needed. Heavy ingots are always heated in pit furnaces, for metallurgical reasons, for saving of floorspace, and for ease of handling by a soaking-pit crane which deposits the hot ingot on an ingot buggy.

The car-type furnace is always selected for heating bulky material regardless of temperature. It serves for temperatures from 1200 F up to 2300 F. The only handling device is a car puller. The general-utility crane does the rest.

Furnaces with rotating hearths are well established for heating objects of intermediate size, especially if their shapes are such that the objects would cause trouble in furnaces of the pusher type. Depending upon the weight of the heating stock, handling devices vary from hand tongs to elaborate charging machines.

In mass production and for heating in the range between 1000 F and 1700 F, automatic conveying is employed almost universally. Which of the many labor-saving devices described in Chapter V is most suitable in a given case depends upon many circumstances that are too numerous to be discussed here.

An extremely interesting problem is furnished by the question:

Shall cold-rolled strip be annealed in coils (batch annealing) or shall it be annealed as a single-thickness strip in continuous (tower-type) furnaces? Before entering into the discussion a glance at the two

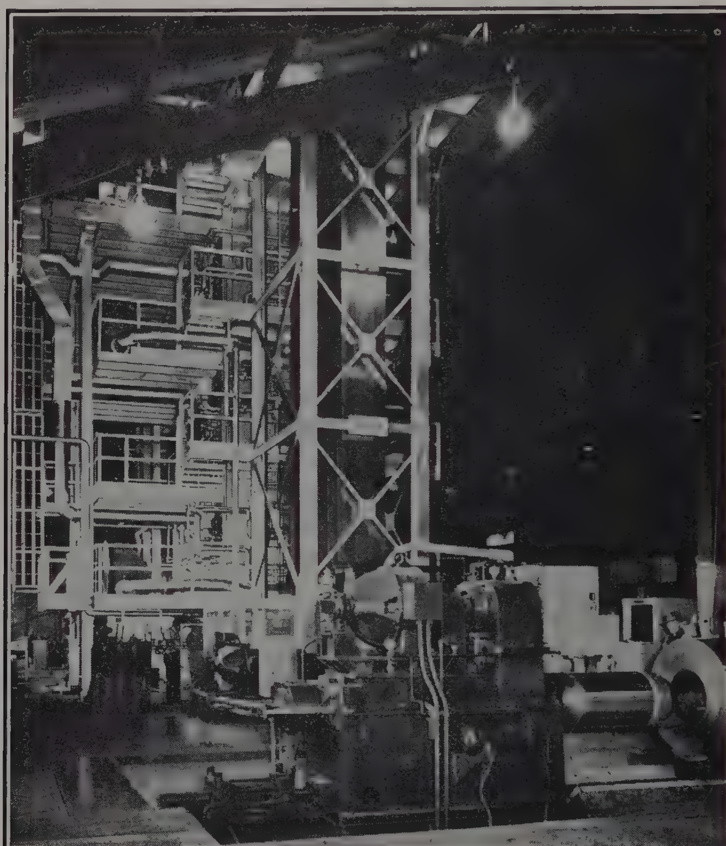

Fig. 300. Tower furnace for continuous annealing of strip. Courtesy of the Drever Co.

types of installations may be appropriate. Fig. 300 shows a continuous tower furnace, and Fig. 301 illustrates an installation of bell-type furnaces for batch annealing.

Either of the two annealing methods has staunch supporters. Actually, the correct decision concerning the most suitable method requires the study by (and the combined efforts of) metallurgists and engineers.

Continuous annealing has been in operation since 1930 for rates from 50 lb/hr to 30 tons/hr. A number of metals have been annealed

by this method: gold foil, nickel foil, beryllium copper, silicon steel, and tinplate. The following facts favor continuous annealing:

1. It promotes a fine grain size and a desirable stiffness in the finished article.

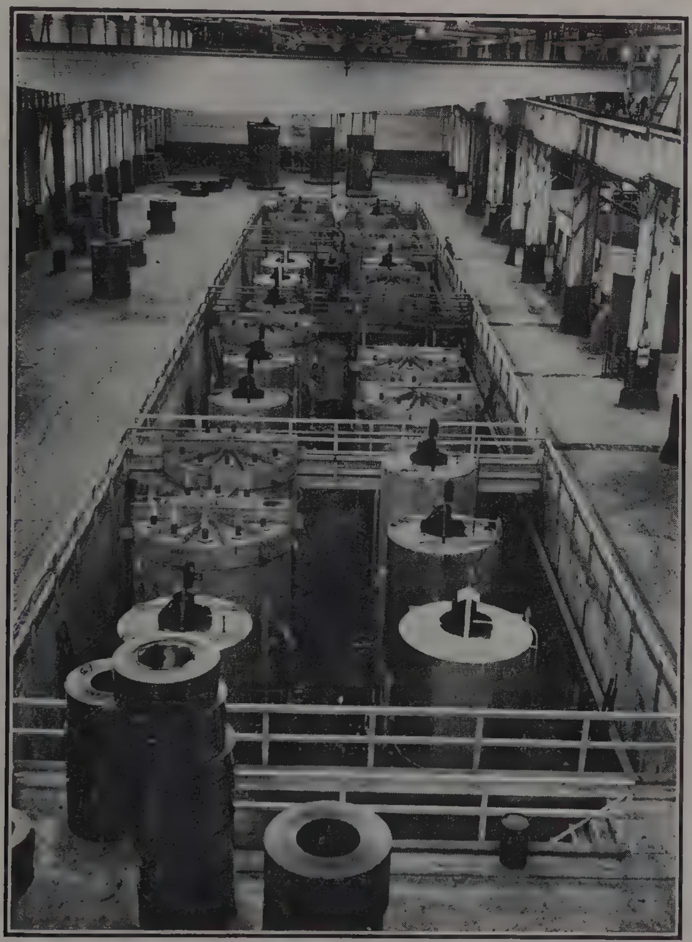

FIG. 301. Group of batch-type furnaces for the annealing of coils. Courtesy of Lee Wilson Engineering Co.

2. In continuous annealing, the preparatory cleaning operation is incorporated in the process. Continuous annealing does not require a separate operation.

3. Continuous (tower) annealing requires less floorspace than is needed by other methods.

TABLE XIX*

COMPARISON OF CONTINUOUS AND OF BATCH ANNEALING, BASED ON A PRODUCTION OF 5000 TONS PER MONTH

	Continuous	Batch
Floor space	8.67 sq ft	12.17 sq ft
Capital investment	$1.4	$1.0
Fuel consumption	500,000 Btu/ton	1,000,000 Btu/ton
Atmosphere, cu ft/ton	822	1,370
Maintenance	Same	Same
Inventory	100 coils ahead 50 coils cooling	100 coils ahead 400 coils cooling
Labor for cleaning	—	0.25 man hrs/ton
Labor for annealing	0.39 man hrs/ton	0.32 man hrs/ton

* From a paper presented in 1950 before the Chicago Regional Meeting of the American Iron and Steel Institute.

4. Annealing temperatures above 1600 F can be carried without damaging the strip, whereas the edges stick in coil annealing at that temperature. In order to prevent sticking of the coil edges in batch annealing, a coating such as manganese chromate, is applied; this means an additional operation plus a cleaning operation after annealing.

5. On account of the speed with which the strip passes through a tower furnace, but little strip is tied up in a tower furnace in comparison with the weight of strip that is tied up in annealing furnaces of the batch type.

6. A correctly designed tower furnace is flexible and can be adjusted to a wide range of time-temperature cycles, both in the heating zone and in the cooling zone.

The advocates of batch annealing (in coils) make the following claims:

1. Annealing in coils is flexible. Coil sizes can be segregated, loads can be made selective, and cycles can be varied.

2. Coils of brass and of copper annealed in bell-type furnaces come out clean.

3. First cost and operating cost per ton of throughput are only a fraction of the corresponding costs for the tower furnace.

The claims are very far apart; as usual, the truth lies in the middle. A comparison made by W. R. Weir, of Dominion Steel, is reprinted here as Table XIX. In order to come out with an even capacity of 5000 tons/month, the batch figures are based on 2⅙ furnaces with 6½ bases using a charge weight of 90 tons. In the continuous process cleaning labor is included in annealing labor.

Since the time when Table XIX was compiled improvements have been made in coil annealing and also in the rolling and welding of strip so that tearing of the strip in a tower furnace does not occur nearly so often as formerly. A tear in the cooling section can be repaired in an hour, but a break in the heating section may require as much as 8 hours before the furnace is again in operation. The figures in the tabulation have changed, but relative costs have remained just about the same.

The comparison may be summarized as follows: For annealing strip of various sizes and compositions at different temperatures, annealing in coils is "tops." Continuous annealing is preferred for mass annealing of strip of constant size and for a fairly wide range of composition. An example of constant size and composition is furnished by strip that serves for making bottle caps (crowns) and tops for jars. Large strip mills are equipped for both methods of annealing. If not, they soon will be.

The comparison also shows that furnace engineers and mill superintendents conspire at all times to reduce operating costs, and that metallurgists tell the conspirators how far they can go.

Comparison of Furnace Atmospheres. The effects of natural atmospheres (products of combustion) and of controlled (artificially prepared) atmospheres are discussed in Chapter IV. In the present chapter the discussion is limited to the question: When should metals be heated in products of combustion or in air, and when should they be heated in a prepared atmosphere? The answer is easy under some conditions and is quite difficult in other cases.

Obviously large ingots of steel are profitably heated in products of combustion. Formation of scale is often desired for the purpose of burning off blemishes, such as cold shots, left from the pouring operation. The scale formed in the heating process drops off in the blooming mill and is returned to the open-hearth furnace or to the blast furnace. Nothing would be gained by heating the ingots in a protective atmosphere, because the decarburized layer is stretched and becomes very thin in the rolling operations.

Contrariwise, objects of soft steel that are to be hardened must be carburized or cyanided (carbo-nitrided) in a prepared atmosphere, which may be gaseous or liquid. Bright annealing of most commercial metals likewise must be done in protective atmospheres.

Between these extreme conditions many situations exist in which the prospective purchaser of a furnace, in consultation with his metallurgist, his head salesman, and a furnace engineer, must make the following decision: Which costs more, expensive heating in a protec-

tive (including cyaniding) atmosphere, or lower quality of product and loss of business caused by heating in products of combustion or in air? As a good reason for this question the following fact may be cited. Steel bars that are heated to a high temperature are decarburized. Often the bars must be heated again for carbon restoration, or else the decarburized and softened skin must be removed by machining. Both processes are expensive.

The conclusion is this: If the annealed pieces are to be machined, heating in a protective atmosphere is an unnecessary expense. And if a coat of scale on the finish-heated pieces does not reduce the sales price, heating in a protective atmosphere is likewise an unnecessary expense. If either bright annealing or carburizing or cyaniding is the object of the heating process, then the introduction of a prepared protective atmosphere is a necessity.

In the decision, the following facts may be useful: Atmosphere furnaces are more expensive than direct-fired furnaces. The cheapest protective atmosphere costs approximately 9 cents per 1000 cu ft. The relative costs of different atmospheres are given on page 195. The cost of "atmosphere" per ton of heated material is, of course, the product of cu ft of atmosphere gas (per ton) times cost per cu ft. No general rules exist for finding the consumption of atmosphere gas per ton of heated material, because that consumption varies within extremely wide limits. Method of handling the charge into and out of the furnace is of paramount influence on the volume of "atmosphere." Builders of furnaces and of generators of protective atmospheres have gathered much information (sometimes at the expense of the customer) on average consumption of atmosphere gases. For obvious reasons, these builders usually recommend gas generators that are larger than needed in normal operation. A standard figure for bell- or hood-type furnaces is 15 cu ft per hour and per foot of length of sand seal. In tests made by the author the sand seals were deep and were well tamped down. In consequence, a gas consumption of less than seven cu ft/(hr, ft of length) gave perfect protection.

Displacing the air from a furnace requires a great volume of atmosphere gas. This fact can be realized from a simple analogy. It is impossible to pour a cup of clean water into a cup of dirty water and have only clean water in the lower cup at the end of the pouring process. If four more cups of clean water are poured in, the lower cup contains water that is practically clean. Furnace engineers purge a furnace with five furnace volumes of atmosphere gas similarly. Very slow purging requires less protective gas than is needed in rapid purging. The latter method produces much turbulence and mixing.

In furnaces that have doors, consumption of atmosphere gas varies with tightness of doors, with frequency of door openings, and with the atmosphere outside the door. For muffle furnaces the Surface Combustion Corporation has published some data, an abstract of which is presented in Table XX.

TABLE XX

Size of Muffle, in.	Atmosphere Gas for Rapid Purging, cu ft per hour
12 × 10 × 31	180
22 × 14 × 38.5	300

On the basis that five furnace volumes of atmosphere gas result in a sufficient purge, the small muffle is purged in 3.6 minutes, whereas the larger muffle is purged in 7 minutes. The difference is caused by the fact that gas generators are built in definite sizes or steps. In consequence, the ratio of generator capacity to furnace volume cannot be kept constant.

If the doors are tight and are opened infrequently, and especially if a vestibule is provided outside the door or doors, the gas consumption given in the table for rapid purging is much too large for normal operation. For that reason, a small generator is often combined with a storage tank for atmosphere gas.

On the other hand, in a roller-hearth furnace for heat treating long pipes or bars, the doors must necessarily be open all the time. Then the purging process does not determine the rate of flow of atmosphere gas; the flow is determined by continuing leakage. Quite obviously no vestibules can be arranged. In a certain furnace of this type, the width of the door is 4 ft and the door is raised 4 in. For protection of the heating stock, a flow of 15,000 cu ft/hr of protective gas is required in spite of wire screens and asbestos ropes that hang down and rest on the charge, which in this case consists of tubes. If the tubes were in short pieces, they could be pushed or rolled through the furnace on trays. The doors could be kept closed most of the time, and protective vestibules could be provided outside the doors. Then the consumption of protective gas would be only a small fraction of the value given above.

In mass production, the use of special atmospheres that are prepared in detached gas generators is now the rule in heating for annealing, carburizing, and cyaniding. As mentioned and described in Chapter IV, steel is being heated to 2200 or even 2350 F, without scale formation and without the use of a separate gas generator. The method

is illustrated by Figs. 166 and 167. The question is: When is the use of this method advantageous, and when does it offer no advantages? The method of heating steel in hot products of very incomplete combustion is profitable in the heating of steel for drop forging and for press work. The absence of scale prolongs die life. The steel need not be heated to a dripping wash heat; no slag is formed in the furnace.

The introduction of this method into general steel-works practice meets with the following realities: As previously mentioned, formation of scale on steel ingots is often beneficial. If the decarburized surface layer is detrimental the skin material is burned off by a ring of oxygen jets after the steel has passed through the blooming mill. At the time of this writing (1954), most steelmill engineers have not been convinced that scale-free heating of blooms and slabs to rolling temperatures is profitable. They point out the high first cost and the cost of maintenance. High-temperature heating in a self-generated protective atmosphere that is the result of very incomplete combustion is advantageous for certain special processes that require absence of scale in hot forming. It is also advantageous in the scale-free heating of some alloy steels. Whereas scale readily drops off carbon steel, it sticks closer than a brother on certain alloy steels. The scale is rolled into the metal and can be removed only by pickling. Prevention of scaling on such steels is desirable and profitable.

This is as far as a comparison of furnace atmospheres can be carried in a book on industrial furnaces.

Selection of Source of Heat Energy and of Furnace Type

After the completion of this critical comparison, the question arises: How can these data be utilized in the simplest manner if a new furnace or a group of furnaces is to be selected? It is evident that the crude method of selecting sources of heat energy solely on the cost-per-Btu basis is a failure and that some other method must be adopted. Unfortunately for the purchaser, no formula exists into which the variables can be substituted and which automatically furnishes the correct answer. It should, however, be possible to evolve a logical process of reasoning which can be followed, with some variation, in each individual case. The following section is an attempt to evolve such a process. It is also intended to show, by means of examples taken from actual practice, to what extent accidental circumstances determine the selection.

If a manufacturer needs a furnace he may select the equipment in

various ways. (1) He may consult a commercial register that gives the names and addresses of manufacturers of furnaces, or he may obtain the information from the advertisements in the technical press; he will then state his requirements in a general way to the furnace builders and make his selection from the bids and designs submitted, being guided by the advice which the sales engineers of the manufacturers volunteer.

(2) If he prefers, he may take his problem to a consulting engineer, who will pick out the most suitable equipment for his needs.

(3) Or, finally, he may go to workshops where similar work is being done, observe furnaces and results obtained in actual operation, and select that equipment which promises the best all-around results when applied to his own conditions.

The last course is very frequently followed for important furnaces because the manufacturer is then certain that he will not meet with any unpleasant surprises, delays, or experiments if he installs a furnace just like the one which has been working successfully for years in some other plant. On the other hand, this method of procedure retards progress if it is followed too slavishly. New types of furnaces, new sources of heat energy come up from time to time, and someone must be the first to try them and introduce them. The ultraconservative man who never installs anything except what someone else has been using successfully for years may find that, in a year or two, he has equipment which is very much out of date, and he may regret his conservatism.

If the new furnace is to be an important one, it is advisable to combine all three methods. If a very small furnace is to be purchased, it does not pay to go to too much trouble and expense because another furnace can readily be installed if it is found that a mistake has been made in the selection of the first one.

The goal of every manufacturer is this: Source of heat energy and type of furnace should be so selected that the cost of perfect finished goods is a minimum. A perusal of both volumes of "Industrial Furnaces" reveals the fact that a very large number of details or items must be considered before the goal can be achieved. A (by no means complete) list of such items follows:

Cost of furnace, excavation, foundation, recuperator or regenerators, flues and stack; cost of maintenance and repairs; cost of heat left in furnace per unit weight of heated material (this last item involves many details, such as cost of a million Btu produced by fuel or electrical energy, cost of delivery of fuel to furnace and of removal of waste products, cost of auxiliary equipment such as oil heaters, trans-

formers, high-frequency generators, gas cleaners, etc.; it also involves availability of fuel and cost of changing over from one fuel to another fuel).

Cost of wages to heaters; cost of supervision; cost of a shutdown (demand charges and part of the pay roll go on).

Cost of charging and emptying the furnace; cost of rejections or reduction in grade of finished material; cost of scaling and burning, and of processes that remove defects originating in the furnace; cost of atmosphere gas; cost of heat radiated to attendants, reducing production.

Adaptability of furnace to be placed into production line in handling material of different sizes, shapes, and composition.

It takes a clear-headed, experienced furnace engineer to pick out the most suitable combination for a large furnace. One furnace engineer put it this way: A good guess based on long experience is much better than a long analysis by an inexperienced engineer. However, even the best furnace engineers can make mistakes and misjudge conditions.

No man is perfect. In correspondence or in an interview, seemingly small, and yet important, details are overlooked. (The forethought comes afterwards.) For that reason, it is advisable that each furnace builder and each consulting engineer equip himself with a long list of questions that are to be answered, either orally or in writing, by the prospective customer. The latter may be annoyed by the long list, but that annoyance does not compare to the grief caused by using the wrong type of heat energy, the wrong type of furnace, the wrong conveying equipment, by a wrong generator of furnace atmosphere, by misunderstandings concerning who is to furnish what and still other important points.

Of course, cases exist in which a consideration of all of the details mentioned would be absurd and ridiculous. If the owner of a small machine shop needs a furnace for making occasional small forgings and for hardening tools, bolts, and other small objects, he most certainly will not hire a consulting engineer. He goes to a hardware store or looks into catalogues and buys a "hand-me-down" furnace from stock. He does not buy an atmosphere generator, but pack hardens or flame hardens. He may purchase a small salt bath.

A salient feature in the selection of heat energy and of furnace is the question: Shall it be an inexpensive, short-lived, and uneconomical furnace, or shall it be a durable, economical, and, therefore, more expensive furnace?

As may be expected, local conditions affect, and sometimes even

dictate, the selection of fuels and of furnaces. In this sentence the word "local" has a very wide meaning, anywhere from a single factory to a whole continent. In the United States natural gas is now available in localities where it was not available 5 to 10 years ago. At that time, electrical energy was often cheaper than manufactured gas or even oil. The arrival of natural gas has in many places reversed conditions so that natural gas is cheaper than electrical energy. The furnace builder and the furnace engineer must keep their ears to the ground and anticipate oncoming changes. Many countries have no natural gas and no fuel oil except that which is either imported or is made by hydrogenation of coal. In those countries the choice of fuels is obviously narrowed down.

In time of war the firing of industrial furnaces with powdered coal may be condoned. In time of peace, it is considered a nuisance if the furnaces are located in densely populated districts. If the owners of the furnace intend to fire powdered coal right along, the powdered coal must be exceedingly fine, and the stack must be very tall, so tall that the white cloud does not settle on the ground in the town. This requirement of a tall stack is extremely important if the works and the town are located in a valley. The ash of very finely pulverized coal is carried away for miles from the top of a tall stack.

A book on industrial furnaces cannot possibly enumerate and describe all the local conditions that affect the selections of fuels and furnaces. In order to indicate the great variety of local conditions, a few examples are given: The furnace may be located on the ground floor or may have to be located on an upper story. The headroom may be limited. There may be difficulty in disposing of products of combustion or of escaping (usually poisonous) prepared atmospheres. Another local condition is the opinion of the metallurgist. If he insists on slow heating, on a long time of holding at temperature, and upon slow cooling, the furnace will have to be rather large for a given throughput.

Examples from the two world wars will be of interest. In 1917 steel ingots were to be forged under a steam hydraulic forging press. Steam being needed so close to the furnace, it was decided to heat the furnace by coal burned on a mechanical stoker and to generate steam by the waste heat of the furnace. The engineers apparently were not familiar with the practice of heating industrial furnaces by coal. No steam was sent in under the stoker, and the roof over the stoker burned through in a hurry. The stoker was then placed directly under the boiler, and the furnace was fired by oil.

When a natural-gas well was brought in near-by, the enlarged forge

shop switched over to natural gas. The economy-minded management installed regenerative furnaces that are illustrated by Fig. 92 of Volume I, fourth edition. A considerable sum of money was paid for the drawings. Both air and natural gas flowed slowly into the furnace. Most of the combustion occurred in the outgoing regenerators. This condition was remedied by blowing a jet of high-pressure steam into the combustion space. Steam is a ballast that does not support combustion. In general, it lowers flame temperatures. In this example steam increased flame temperature because it mixed fuel and air in the combustion chamber. The increased formation of scale was taken into the bargain. For reasons that are explained in Volume I, the expected fuel economy did not materialize. Twin furnaces, illustrated by Fig. 123 of Volume I, were then installed with the intention of having the waste gas from one furnace preheat an ingot in the other furnace of the set. When the heated ingot had been removed, gas fire was applied to the preheated ingot. Although the twin furnace is very good with regard to slow preheating and to heat salvage, it was abandoned because the heating and forging schedules could not be arranged to suit the furnace. Both furnaces were then fired separately. When the furnaces were rebuilt, the twins were separated. The final design looked like the furnace illustrated in Fig. 196 of the present volume, with the exception that the hearth was solid. The ingots were not large enough to warrant a furnace of the car type.

This "comedy of errors" is proof of the statement that is made in several sections of this book: When fuel economy interferes with process requirements, fuel economy has to get out of the road so as to clear the way for process requirements. This same condition exists today. Blooms and small ingots are heated as rapidly as possible without the formation of cracks. The rapid heating reduces the number of furnaces that are required, as well as scale formation. However, fuel economy is poor because the products of combustion leave while exceedingly hot. Progress is being made in determining the highest permissible rate of heating. It is a function of the composition of steel and of linear dimensions. The majority of furnace builders have let the steel processors do the research work on this subject.

During the Second World War the bodies of demolition bombs were forged in very large numbers. By far the greatest number were produced from tubes, either seamless or resistance-welded. The ends of the tubes were heated for various forging processes. In localities where natural gas was available, gasfired furnaces were preferred. A gasfired furnace for heating the ends of tubes is illustrated by Fig.

287. Tubes that are to be heated in large numbers invite high-frequency induction heating. This method of heating was almost a necessity in one shop, where natural gas was not available at that time. Since natural gas was to be piped to its locality soon after the war, the city gas works could not well be expected to expand its facilities for the purpose of serving the bomb plant. The induction coils were located in the pipe. By virtue of this arrangement, the press die could forge the heated section without loss of time. At the shop in question five heatings and press strokes were successively applied in five presses. Induction heating offers the advantage that heat can be concentrated where needed. Hot metal flows more readily than cooler metal. Axial forces thicken the wall more in the hot zone than in cooler zones. The tube ends were heated so quickly that no furnaces were needed. After the noses had been forged, the tail ends were forged in another set of presses.

The forged bombs had to be heated for quenching and, again, for drawing. On account of the contoured outline of the forged bomb, induction heating was impractical. Oil firing might have been used, but the management decided on butane. The high cost of butane was not objectionable, because the government paid for it. The standard method of carrying the bombs in suspension through the furnace was followed. Occasionally a supporting rod would give way in the hardening furnace, and a bomb dropped to the bottom. The furnace was made so deep under the suspended bombs that the fallen bomb could rest in peace until the next shutdown.

In concluding this chapter it may well be mentioned that, in the early stages of heating for manufacturing a new product, continuous heating is not advisable unless much experimental work has been done. Even then the wisdom of continuous, automatic heating is questionable because the new product may not "take." The most economical furnace with regard to both fuel and labor has no merit if the goods heated in that furnace cannot be sold. Therefore, it pays to start the heating of a new line of goods in furnaces of the batch type, including salt-bath furnaces, and to postpone the installation of continuous furnaces until perfection of process and volume of sales justify the installation of continuous, automatic furnaces. Further pursuit of this reasoning would go beyond the scope of a book on industrial furnaces and would lead into factory management.

CHAPTER VII

SAFETY MEASURES

Injuries to furnace operators have different causes. Among the latter are (1) explosions and flames, (2) electric shock, (3) poisoning, (4) falling and swinging weights. Lesser sources of injury are hot, but seemingly cold, objects that are grasped or stepped on; looking too long into bright, hot furnaces (furnace men's cataract); and heat exhaustion.

Explosions and Flames. Explosions can occur in any direct-fired furnace and in furnaces that are filled with protective and combustible atmospheres. Explosions occur more frequently in gasfired furnaces than in oilfired furnaces. Explosions are rare when the furnace temperature exceeds 1400 F, because at or above that temperature any fuel or explosive mixture entering the furnace is immediately ignited; no dangerous volume of non-ignited mixture can accumulate. Explosions can occur at any time in ovens in which the temperature is less than 1000 F; they occur in furnaces mainly in lighting up from cold start or after a prolonged shutdown.

If fuel gas or vapor or an explosive mixture is admitted to a furnace that does not show color and if a lighting torch is applied, anything between a light puff and a severe explosion occurs. The damaging effect of the explosion is reduced if the furnace doors are open. In that case, the man who applies the torch is burned unless he stands aside and uses an around-the-corner lighting device. Explosion hazards are greatly reduced by pilot flames, several arrangements of which are illustrated in Chapter II. The pilot flames are lighted one by one, and so are the burners. A group of closely spaced burners may be lighted at one time.

In gasfired furnaces the pilot flames are usually fed from a line that branches off ahead of the main control valve. If electric power fails, the safety control valve closes itself automatically. When power "comes on again," the pilot flames are lighted before the tripped safety valve is reset. An independent supply of fuel to the pilot burners, for instance butane, does not contribute to safety unless a supply of air is provided that goes on even after the power fails. Whenever a supply of electric power is available, a very ingenious device that

lights the pilot burners can be used. It consists of spark plugs that are placed at the roots of the pilot burners. They spark at 6- to 10-second intervals. Safety requires that the spark plugs be examined regularly; the tip of each plug becomes red hot in regular operation.

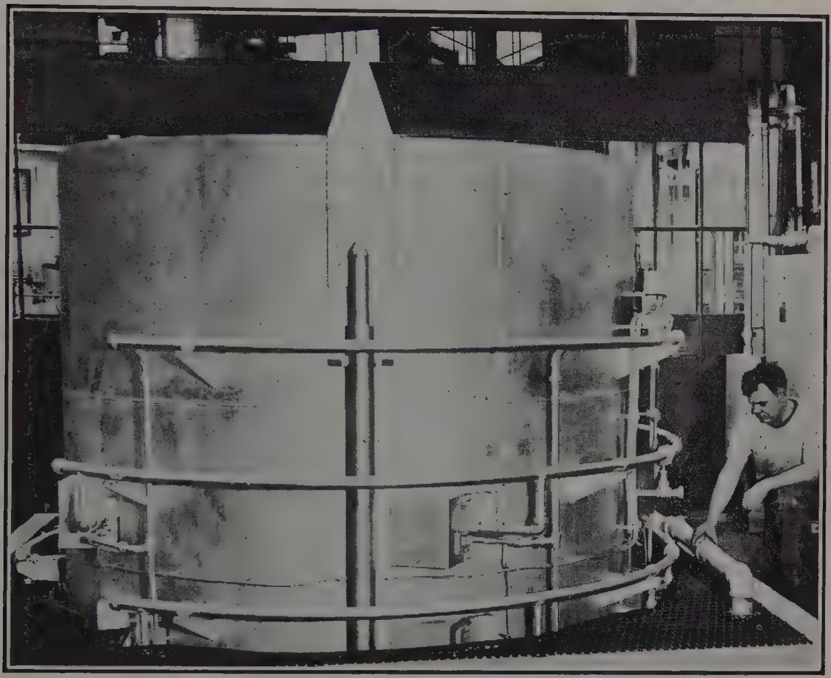

FIG. 302. Furnace equipped with separate gas lines for pilot lights. Courtesy of Westinghouse Electric Corp.

Fig. 302 shows how this equipment is arranged on a cylindrical furnace. The two separate supply lines for burners and for pilots are easily discerned. The wiring for the spark plugs is also clearly visible.

Many safety rules have been laid down by the Associated Factory Mutual Fire Insurance Companies (Factory Mutual, for short) of Boston, Massachusetts. When all possible safety equipment is provided, piping and wiring become complicated, especially if push-button starting is embodied in the equipment. Safety equipment has greatly reduced the number of accidents, but has not entirely prevented them. If, for instance, the main safety shutoff valve leaks and the manually controlled shutoff valve is left open, gas still leaks into the furnace. Equipping safety shutoff valves with soft seats reduces the hazard.

Pilot flames for oil burners are usually fed with gas. The gas consumption is so small that even manufactured gas is not too expensive. If no public supply of gas is available, propane, butane, or vaporized light oil (see page 23) serves very well.

The best safety device is an intelligent and well-instructed furnace operator who has thoroughly familiarized himself with the furnace, the piping, and the control board. In factories with a number of furnaces, safety is enhanced by a burner man, who inspects the equipment at regular intervals and instructs the operators.

The advent of protective atmospheres has introduced a new explosion hazard. Some protective atmospheres contain hydrogen, or carbon monoxide, or both. The most important rule is to maintain furnace pressure at all times and thus to exclude air. Furnace pressure can be maintained automatically. If the furnace temperature exceeds 1400 F, any air that leaks into the furnace is immediately used up for combustion. If air leaks in while the furnace is being heated, an explosive mixture which will let go when heated to the ignition temperature is formed. If the device that maintains furnace pressure during the heating period fails, another device promotes safety. It is an electrically heated tube that causes combustion if air leakage occurs. The hot tube is located near the hearth, because air is heavier than the combustible atmosphere. Safety requires that all the air be expelled from the furnace before the latter is brought up to 1400 F. A very safe method of purging was observed by the author in Germany in the year 1931. Carbon dioxide (inexpensively absorbed from products of combustion in the power plant) was sent into the bottom of the furnace. A flame that burned at the opening at the top of the furnace was extinguished when all of the air had been expelled. The protective, combustible gas was then admitted at the top. When a small flame that burned at the bottom opening ignited the atmosphere gas flowing out of the bottom opening, purging was considered to be complete.

Vestibules constitute an explosion hazard if the furnace atmosphere is combustible. Furnace pressure causes atmosphere gas to flow into the vestibule. If air leaks into the vestibule, an explosive mixture can be formed. The electrically heated tube mentioned above initiates and maintains combustion before enough air has leaked in to cause an explosion at the time when the furnace door is opened.

Electric Shock. Electric shocks are very rare occurrences with modern furnaces. The terminals are protected against being contacted. Nobody is foolish enough to replace a burned-out resistor while the power is on.

If the container (of the charge) for a furnace of the batch type is filled to overflowing, there is danger of part of the charge rolling off, on account of expansion. If the unruly piece contacts the resistors, the furnace is shut down for some time. If the attendant watching through a peep hole notices the danger of the piece's rolling off, he opens the door and pushes the piece back into place. If this operation is performed while electric power is on the furnace, the operator may suffer serious injury. Safety demands that the power be automatically cut off when the door is opened.

In automatic furnaces that convey the charge on continuously moving belts, a never-closed opening must be provided at either end. In such furnaces protection by door switches is possible only against excessive door lift. Pieces of the charge cannot wander off the belt because each belt, whether of the link type or of the woven-wire type, has turned-up edges. Clearance is provided between belt and resistors; if, in spite of turned-up edges, a piece of the charge should drop down, it does not touch the resistors. The operator has no occasion to adjust the charge. If the belt breaks, the furnace is shut down for repairs and the switch is locked.

Poisoning. The principal poisons found in and near industrial furnaces are carbon monoxide and cyanides (fumes and salts).

Carbon monoxide is a constituent of many gaseous fuels (see Table I), and leaks in supply pipes are dangerous. Supply pipes are furnace auxiliaries; their design, construction, and maintenance are outside the scope of this book. It should, however, be mentioned that carbon monoxide has no odor and that its molecular weight is 28; this is close to the molecular weight of air, which is 29.

Carbon monoxide is also a constituent of several protective atmospheres. While charging or emptying vestibules, the furnace attendant may get a dose of the poison gas. However, the danger of serious effect is practically absent. The operator stands at some distance from the door; carbon monoxide is a part only of the atmosphere gas, and the operations are performed quickly in order to keep as much protective gas as possible in the vestibule.

Atmosphere furnaces having continually open doors are equipped with hoods in which a flame is kept burning for the purpose of burning most of the hydrogen and the carbon monoxide. Or the escaping atmosphere is vented through ducts that lead into the open. Overhead operators of traveling cranes are more likely to be affected by poisonous gases than furnace operators are.

Cyanide fumes are extremely poisonous. For that reason, cyanide-salt pots are equipped with hoods that draw the fumes away from the

attendant. This device is illustrated in Fig. 303. In addition, cyanide pots are usually located on the top floor of the factory. And finally, the operators are equipped with gloves, aprons, and gas masks. Many cyanide pots have been replaced by dry-cyaniding furnaces.

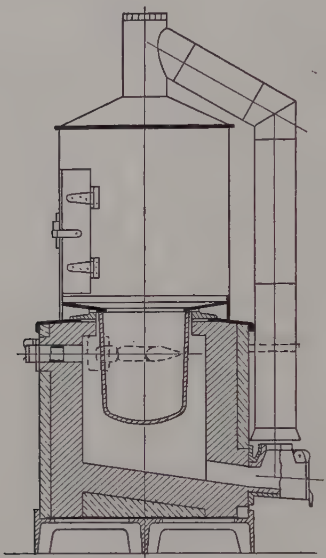

FIG. 303. Salt bath with hood for carrying poisonous vapors away.

Falling and Swinging Weights. Quite obviously no weights can drop on a man in the furnace when the furnace is in operation. While the furnace is being constructed or repaired, the usual precautions are taken. While the furnace is in operation, vertically traveling counterweights of doors can descend quickly on the foot of the operator. A rigid shield around the counterweight prevents accidents.

Falling or swinging weights on the outside of the furnace can severely injure furnace operators. The prevention of accidents by falling and swinging weights is not a problem of furnace engineering, but of design and operation of charging machines and of cranes. The best furnace design cannot keep a crane operator from picking up a heavy load on a slant and from starting or stopping too suddenly. Furnace operators have been severely injured by being caught between a swinging load and a furnace.

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